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The Dependent Converging Instrument Approach Procedure: An Analysis of Its Safety and Applicability

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16. Abstract

When an airport experiences low ceiling or visibility conditions the arrival capacity is significantly reduced. This is particularly true at airports that use both their main runway and their crosswind runway in Visual Meteorological Conditions (VMC). The consequence of this is an increase in delays. A concept for continuing to conduct approaches in Instrument Meteorological Conditions (IMC) to converging runways has been proposed which calls for coordinating the approaches to the two runways such that a stagger between the aircraft is maintained. This procedure is known as Dependent Converging Instrument Approaches (DCIA). This paper develops a DCIA procedure applicable to any runway geometry. The procedure is defined and modeled to capture its safety critical aspects. From this analysis recommendations are made concerning the stagger values and other factors relevant to applying this procedure safely.

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EXECUTIVE SUMMARY

INTRODUCTION

When an airport experiences low ceiling or visibility conditions the arrival capacity of the airport is significantly reduced. This is particularly true at airports that use their main runway and a crosswind runway in visual meteorological conditions (VMC). For these airports the capacity is effectively reduced to that of a single runway operation. The consequence of this is an increase in delays.

In 1986, the Federal Aviation Administration (FAA) issued an order (FAA Order 7110.98) that instituted simultaneous converging instrument approaches (SCIAs). That order allows airports with converging runways to conduct operations to both runways under certain ceiling and visibility conditions that are less than VMC. However, because the procedure provides for the safety of the simultaneous operations with turning missed approaches, the minima tend to be quite high because the protection areas cannot overlap. The order also limits the operations to a minimum of 700 feet ceiling or 2 mile visibility for intersecting runway geometries. To date only four airports (Philadelphia, Dallas-Ft. Worth, Denver, and Washington Dulles) have utilized the provision of this order to reduce the minima to which they may use their converging or intersecting runways.

In the late 1980s another concept for conducting approaches to converging runways was proposed. In its final version, this procedure called for coordinating the approaches to the two runways such that a stagger between the aircraft[1] is maintained. This stagger would insure that if both aircraft had to miss their approaches, separation between them would be guaranteed even at the intersection of their flight paths. This procedure, which is named the dependent converging instrument approach (DCIA), is predicated on protecting against consecutive straight-out missed approaches, and the minimum required stagger distance is set accordingly.

Experience in the laboratory has shown that setting up and maintaining such a stagger is a skill that is difficult for controllers to apply consistently. Therefore an automation aid to assist controllers in achieving the required stagger has been proposed. This aid has become known as the converging runway display aid (CRDA). The aid can be described with reference to figure ES-1. For every aircraft A on approach to one runway (R1) there is a

1 A stagger between aircraft is the difference between the distance of one aircraft to the runway centerline intersection point and the distance of the other aircraft to the runway centerline intersection point.

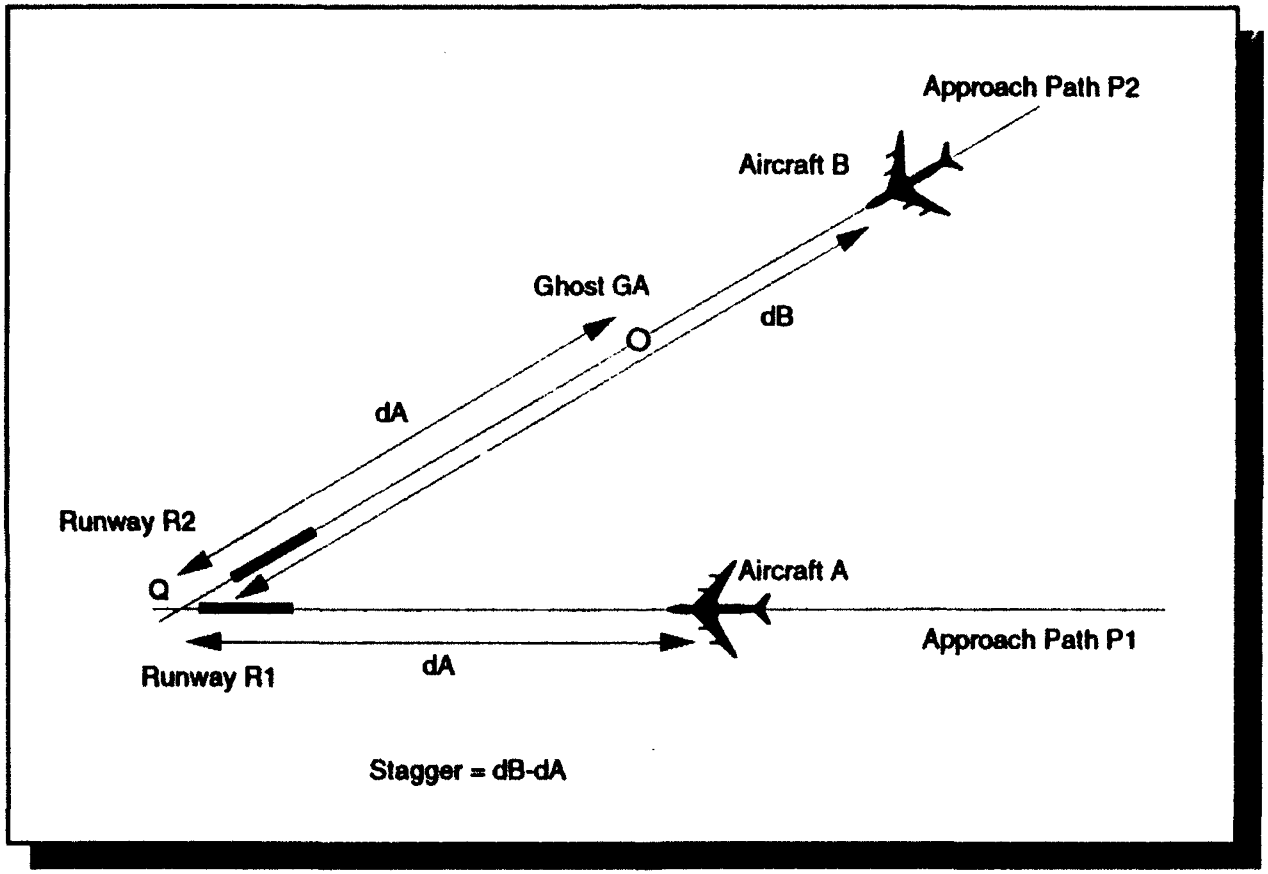

Figure ES-1. The Converging Runway Display Aid Concept

ghost target GA displayed along the other approach path (P2) for converging runway R2 such that the distances of the ghost target GA and the real target A from the point of intersection of the two runways or their extended centerlines are equal. The position of the ghost target is updated every radar scan along with the update of the real target. Aircraft B is the trailing aircraft on the converging approach. The controller is required to establish a spacing between the ghost target GA and aircraft B. The vectoring of an aircraft to follow another target on a radar scope is a controller skill that is highly developed.

PURPOSE

The purpose of this paper is to develop a DCIA procedure applicable to as many runway geometries as possible within certain defined constraints. The procedure is defined and modeled to capture its safety-critical aspects. From this analysis recommendations are made concerning the stagger values and other factors relevant to applying this procedure safely to a wide variety of runway geometries.

This paper discusses the procedural and safety aspects of the DCIA procedure rather than issues pertaining to automating the CRDA. The analysis presented in this paper deals with the DCIA procedure as it applies to any runway configuration. Worst-case considerations are used as the basis of this general analysis. Finally, some specific examples are provided to illustrate the point that even though an airport could benefit from the general DCIA procedure a more specific analysis leading to a specific DCIA procedure for that airport might provide even greater benefit.

ATC BASIS OF THE DEPENDENT CONVERGING INSTRUMENT APPROACH PROCEDURE

The basic principle behind DCIAs is to coordinate arrivals on converging approaches such that the two aircraft may approach the runways with adequate stagger. In the unlikely event that the aircraft on the two approaches should both conduct missed approaches, the stagger provided on approach is designed to be such as to guarantee that the aircraft will be separated during their missed approaches without requiring any further intervention by the controller. The procedure thus guarantees safe passage even in the event of radio and radar failure.

DCIAs provide for aircraft separation during missed approach when the minimum stagger is achieved as the leading aircraft reaches its runway threshold by:

1. Utilizing straight-out published missed approaches

2. Assuring procedural (i.e., non-radar) separation between aircraft and protection from wake turbulence during missed approaches by requiring that there exist a minimum stagger between arriving aircraft and

3. Establishing values for the required stagger on approach to account for aircraft speed and performance variations, and the effects of different runway geometries and winds

The DCIA procedure uses provisions already contained in the FAA Air Traffic Control Controller's Handbook (FAA Order 7110.65) to develop requirements for the safe conduct of DCIA procedures, utilizes radar control procedures to achieve the necessary stagger on approach, and assures adequate separation by enforcing non-radar separation standards when radar or radio contact is lost during consecutive missed approaches.

GENERAL DESCRIPTION OF THE DCIA MODEL

From analyses of converging consecutive missed approach scenarios it was determined that the primary determinants of the final separation between aircraft at the runway centerline intersection are:

- Initial stagger
- Ground speed differential of the two aircraft
- Ground speed of the leading aircraft
- Relative accelerations of the aircraft
- Wind speed and direction and
- Runway geometry

Distances from runway thresholds to the intersection of the runways (or their extended centerlines) are modeled directly. The included angle between the converging runway approaches and the effects of the wind are modeled indirectly by assuming worst-case geometries.

In the DCIA model, the approach and miss profiles of a given aircraft are considered in four phases:

1. An aircraft is assumed to cross the outer marker at some fixed nominal airspeed.

2. Starting at the outer marker the aircraft decelerates at a constant rate; the rate is chosen so that final approach airspeed is achieved in a specified distance.

3. The aircraft maintains its final approach speed until it reaches its missed approach point.

4. Starting at the missed approach point the aircraft accelerates to a constant missed approach speed determined by the aircraft type.

Aircraft are assumed to fly the heading of the runway until passing the runway centerline intersection after executing the miss.

The DCIA model systematically analyzes combinations of pairs of aircraft making missed approaches as described above. The DCIA model is used to determine the conditions under which a horizontal separation (in the case of a leading non-heavy aircraft) or a time separation for wake vortex avoidance (in the case of a leading heavy aircraft) is required. The DCIA model assures adequate separation even for the following combination of deleterious events:

- The leading aircraft misses its approach,
- The stagger between the aircraft is the minimum allowed,
- There is no radio contact with either aircraft,
- The trailing aircraft misses its approach,
- The weather conditions preclude "see and avoid" techniques by either aircraft,
- The wind conditions are such that the worst allowable wind is operative at the time of the consecutive missed approach event,
- For some reason the leading aircraft cannot or does not accelerate, while the trailing aircraft accelerates to the intersection even though dependent staggered approaches are in effect, and
- The combination of aircraft is such that there is a significant speed differential between the two aircraft, and the slower aircraft is the leading aircraft.

MODEL VALIDATION AND IMPLEMENTATION

The missed approach was developed to conform to reasonable expectations of knowledgeable individuals (in this case, pilots, operational personnel, and FAA staff). It was based on previous analyses and simulations of missed approach dynamics including a comparison to staged consecutive missed approaches conducted at St. Louis in July 1991

using actual aircraft. That previous work was reviewed by FAA Technical Center staff whose written report endorsed the methodology and findings of those analyses and simulations.

The DCIA model was also checked for internal consistency over the range of parameters of interest. In addition, the model was implemented in two forms with one implementation having more detailed acceleration assumptions to check accuracy of the models and calculations. The differences between the two implementations of the model were negligible.

The model relates the dynamics of missed approaches, runway geometries, stagger values, and winds to the resulting aircraft separations at the intersection of the runways over a range of values of the pertinent parameters. The FAA's Air Traffic and Flight Standards organizations established the ranges of values listed in table ES-1 as those that provide adequate safety and reflect the expected operational and environmental conditions.

The parameters in table ES-1 are self-explanatory with the exception of "Forms of restrictions." It turns out that only a subset of the runway geometries can support all of the speed groups of aircraft using a particular stagger rule. In order to include other runway geometries, certain aircraft need to be restricted to a particular runway. In some cases restricting slower approach speed aircraft to the runway with the shorter threshold-to-intersection distance is sufficient. In other cases just not pairing certain groups of aircraft is sufficient. For a given stagger distance there are some very fast or very slow aircraft that are exceptions and cannot be handled. Therefore, the procedure can be run for all aircraft except those listed. In actual operations the controllers would let those aircraft land but a larger stagger would be necessary. Combinations of these restrictions are also allowed.

ANALYSIS PROCEDURES

For any two runways whose extended centerlines intersect, the DCIA model yields the distance and time separations of the aircraft at the intersection. The analysis proceeds by assuming combinations of values for the operational parameters listed in table ES-1 (except for the "Forms of restrictions" and "Minimum separation at intersection"). The DCIA model finds solutions that provide adequate separation for cases in which the leading aircraft (at the start of the scenario) gets to the intersection first. Separation at the intersection is an issue only to the extent that the trailing aircraft is faster than the leading aircraft. Under these conditions, the longer the runway threshold-to-intersection distances are, the smaller will be the separation of the aircraft at the intersection. Therefore, the analysis is performed by

Table ES-1. Parameters for the Analysis of DCIAs

Parameter	Values
Minimum separation at intersection	1 nmi for non-heavy leading aircraft 76 seconds for heavy leading aircraft
Included angles between the runways	30 degrees minimum 120 degree maximum
Approach airspeed at Outer Marker	174 kts
Final approach airspeeds	80 kts minimum 170 kts maximum 10 kt increments
Missed approach accelerations	Equivalent to the maximum effective acceleration to the intersection for the aircraft using St. Louis with a maximum speed of 250 kts
Distance from runway threshold-to-intersection	0 feet minimum 27,300 feet maximum 100 foot increments
Winds	30 kts maximum 15 kts maximum crosswind 5 kts maximum tailwind
Form of restrictions	● Restrict x kt or less aircraft to runway with shorter threshold-to-intersection distance ($80 \leq x \leq 120$) ● Except y kt or greater aircraft ($y \geq 160$) ● Except s kt or less aircraft ($s \leq 90$) ● Do not pair z kt or less aircraft leading with y kt or greater aircraft trailing ($z \leq 110$, $y \geq 160$) ● Restrict and do not pair ● Restrict and except ● Except and do not pair
Decision Heights	250, 500 and 700 feet
Stagger	2, 2.5 and 3 nmi for non-heavy leading aircraft 5 and 6 nmi for heavy leading aircraft

determining the maximum threshold-to-intersection distances for which a given set of restrictions and operational parameter values suffice to meet the minimum separation-at-intersection requirements.

This pair of maximum threshold-to-intersection distances (i.e., the shorter and longer distances from threshold to intersection) is called a breakpoint. An initial breakpoint is determined for which the two threshold-to-intersection distances are equal. Then, additional restrictions and larger stagger distances are imposed to obtain larger long-threshold-to-intersection distance breakpoints. Any pair of runways whose short and long threshold-to-intersection distances do not exceed those of a given breakpoint can be safely operated using the operational parameters and restrictions that determined that breakpoint.

RESULTS

General Results

As described above, the analysis methodology was designed to find those ranges of runway threshold-to-intersection distances for which a common set of operational conditions would allow a safe operation. Each set of operational conditions is a DCIA procedure. An example of one subset of these procedures is shown in table ES-2. This table indicates that for a airport with runways whose shorter and longer lengths from the runway threshold to the runway intersection point are as shown in the left-most two columns, there are five safe procedures as indicated in the DCIA Procedure column. As the required stagger (indicated in the parentheses) becomes greater, the restrictions become less severe. For example, the procedure "None (3,5)" indicates that with a stagger of 3 nmi behind a non-heavy aircraft and 5 nmi behind a heavy aircraft all aircraft can land on either runway without regard to the traffic on the other runway except to provide the required stagger (i.e., none of the aircraft are restricted). An "Excepted" aircraft is one that cannot be safely accommodated with the given stagger values. The rightmost column indicates the increased stagger that is necessary to accommodate the "excepted" aircraft. In all cases, skipping a slot in back of an "excepted" slow aircraft or in front of an "excepted" fast aircraft will suffice to maintain a safe operation. If the procedure does not involve an "excepted" aircraft, additional stagger is not applicable (denoted NA).

The range of distances from threshold-to-intersection in table ES-2 is only one of many that were found with the DCIA model. Consider the continuum of longer and shorter distances from threshold-to-intersection as shown in figure ES-2. The range of distances in table ES-2 is depicted in figure ES-2 as the shaded cell. Each of the other cells in figure ES-2 have corresponding DCIA procedures. For longer and shorter threshold-to-intersection distances not covered by the cells in figure ES-2 there is no DCIA procedure.

Table ES-2. Example of a DCIA Procedure for Decision Height of 250 Feet

Shorter Distance from threshold to intersection	Longer Distance from threshold to intersection	**DCIA Procedure** Stagger aircraft to converging runways using indicated stagger distance; restrictions noted	Stagger rule for "Excepted Aircraft"
2601 ft to 3400 ft	3401 ft to 4000 ft	○ Restrict 90 kt or less aircraft to runway with shorter threshold-to-intersection distance **and** except 80 kt or less aircraft; **stagger rule is (2,5)**	(2.5,5) or skip a slot
		or ○ Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2,5)**	(3,5) or skip a slot
		or ○ Restrict 80 kt or less aircraft to runway with shorter threshold-to-intersection distance; **stagger rule is (2.5,5)**	NA
		or ○ Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	NA
		or ○ None; **stagger rule is (3,5)**	NA

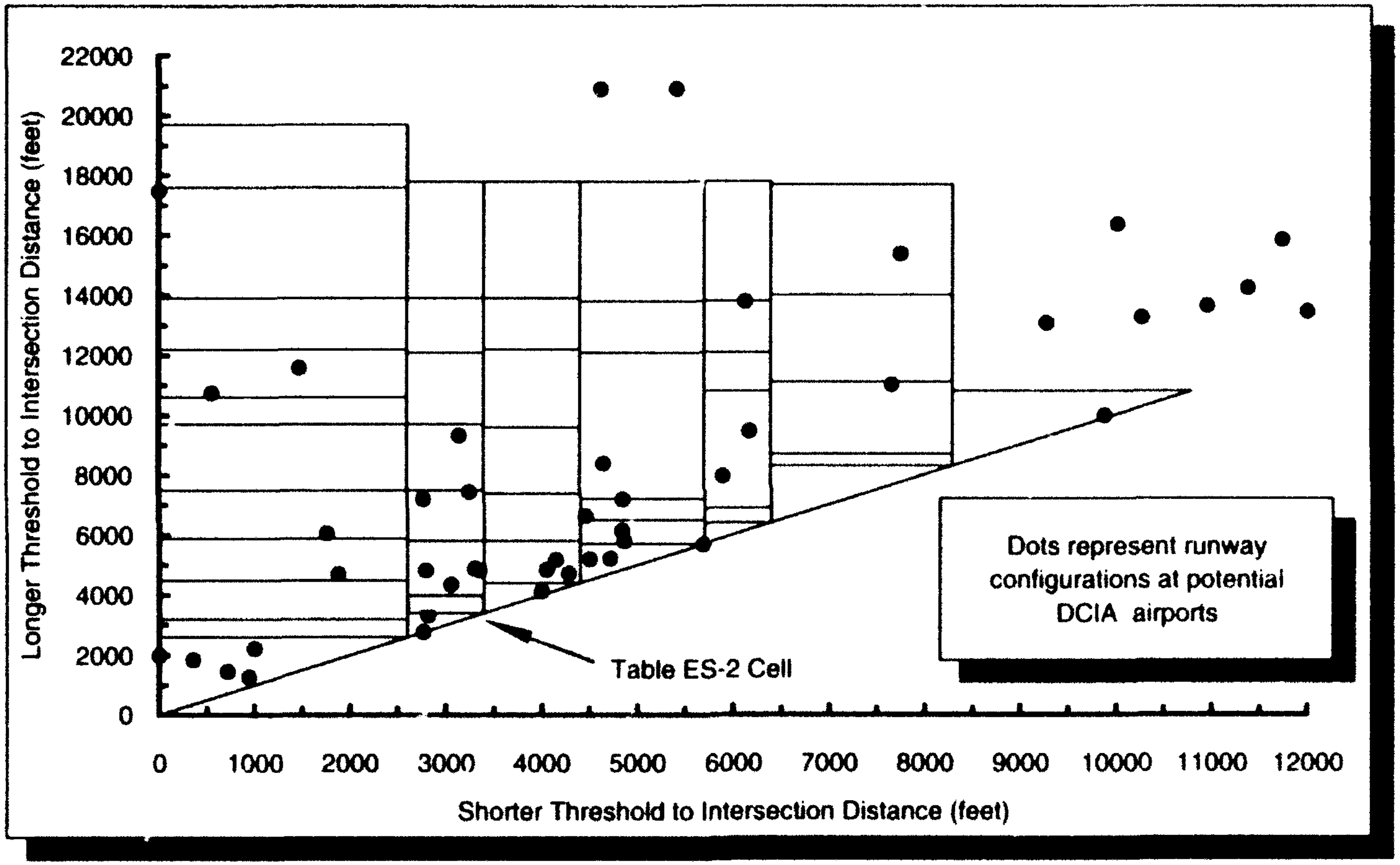

Figure ES-2. DCIA Procedure Regions for Decision Heights < = 250 Feet

The dots on figure ES-2 present runway configurations among the top 100 airports with a potential for using the DCIA procedure. For any airport that wants to determine a DCIA procedure that would be applicable to that airport, the appropriate cell and the corresponding DCIA procedures could be identified.

Since the possible DCIA procedures (i.e., restrictions and stagger rules) vary with decision height, figures ES-3 and ES-4 show the cells for decision heights between 250 and 500 feet and between 500 and 700 feet, respectively.

Site-Specific Results

Runway lengths, the included angle between the converging runways, and the decision height(s) were modeled for a generic rather than an actual site. Also, the DCIA analysis was carried out with a simplified acceleration model. These simplifying assumptions lead to DCIA procedures that may be more conservative at specific sites than is needed.

As an example, two specific sites are considered: Chicago O'Hare runways 27R and 32L, and Philadelphia International runways 9R and 17. The runways at Chicago O'Hare have an included angle between the runways of approximately 50 degrees which results in more benign winds than do the included angles assumed in the general DCIA model. The Philadelphia runways are an example of an asymmetry in distance from the threshold to the intersection for which the general model yields very conservative results.

The general results would require a 3 nmi stagger behind non-heavy aircraft in the Chicago example. With site specific modeling and with a knowledge of the type of traffic that primarily uses Chicago O'Hare, a 2 nmi stagger behind non-heavy aircraft is possible. For the Philadelphia configuration, the general results would require a 2.5 nmi stagger behind non-heavy aircraft and a 6 nmi stagger behind heavy aircraft. With site-specific modeling, an asymmetric stagger could be used to increase the arrival rate at the airport.

RECOMMENDATIONS

Recommendations for Implementation

The DCIA procedure is capable of supporting the DCIA concept in the current ATC environment at a significant number of airports using available technology. The conditions under which the procedure can be run have been developed. Although the procedure definitions are not unique, they are easy to implement at various facilities. For this reason, we recommend that the implementation of the DCIA procedure through an FAA order be based on the procedures developed in this report.

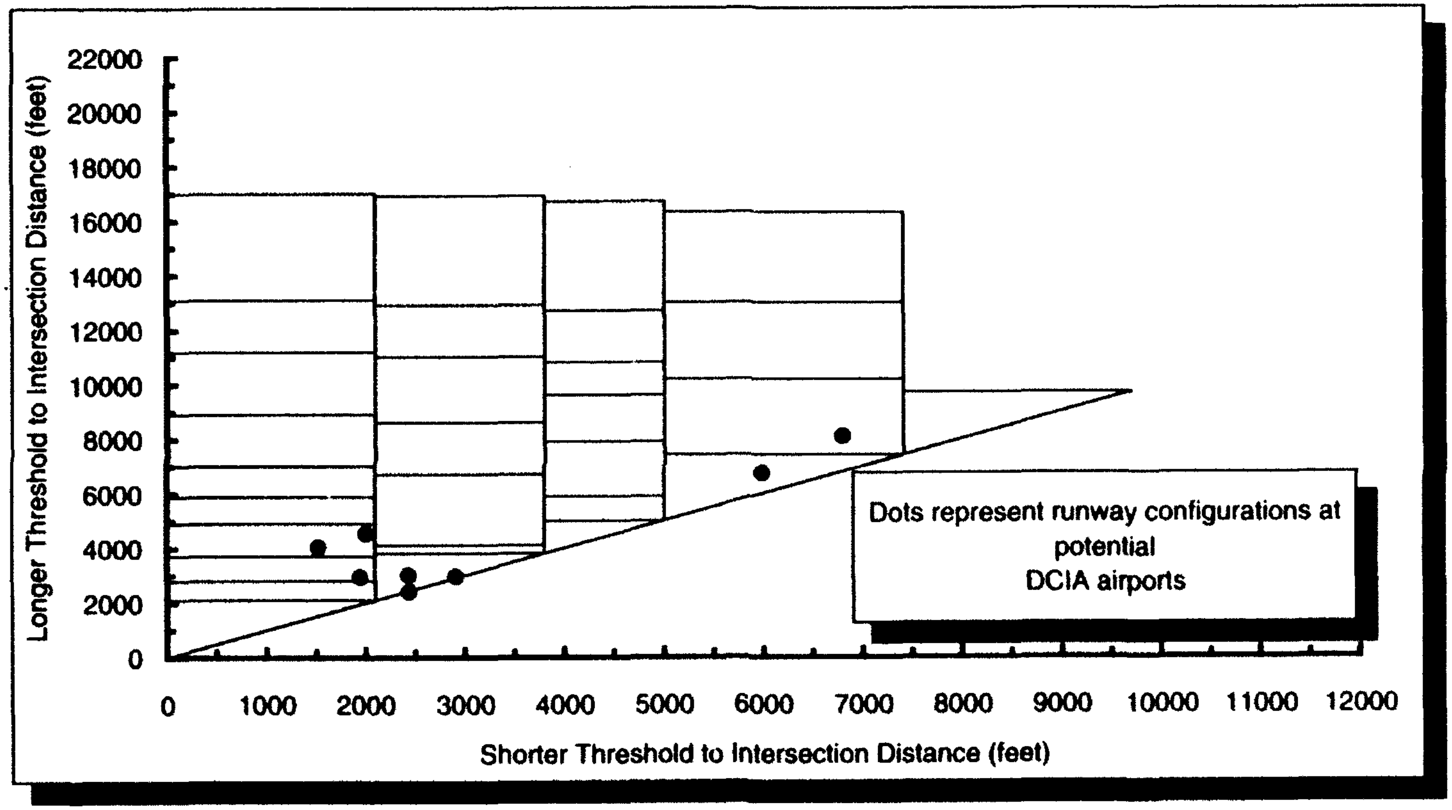

Figure ES-3. DCIA Procedure Regions for Decision Heights > 250 feet and < = 500 Feet

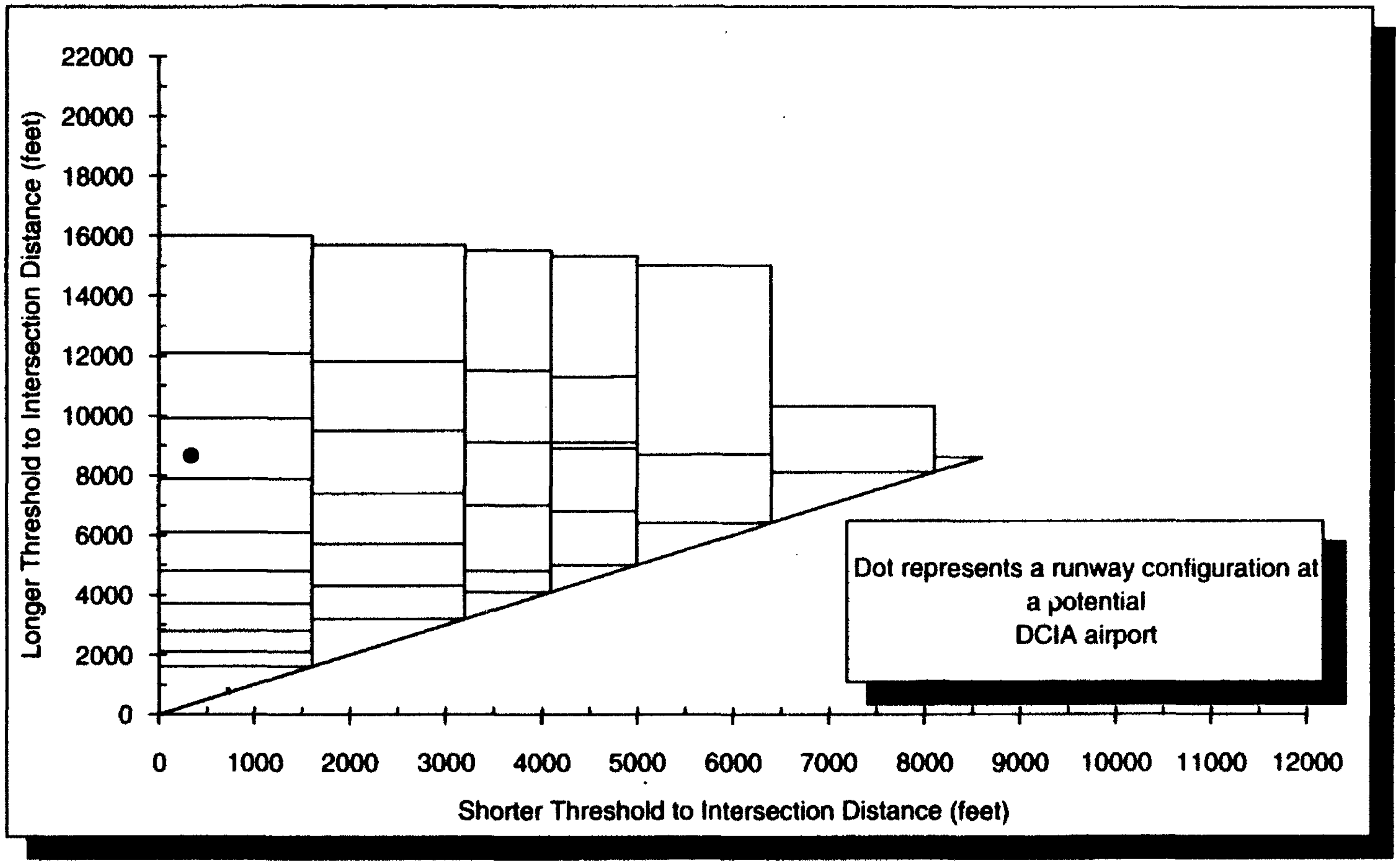

Figure ES-4. DCIA Procedure Regions for Decision Heights > 500 feet and < = 700 Feet

Because the general procedures are very conservative, some facilities would benefit from site-specific analysis. Therefore, we recommend that for those airports with significant traffic levels or with other unique considerations (e.g., the runway with the shorter threshold-to-intersection distance is really the airport's main runway) procedures be based on site-specific analysis rather than the generic analysis.

Recommendations for Future Work

The procedure as discussed in this document is designed to be simple for easy operational use in the current system. It contains several restrictions that are considered necessary for a first step. Many of the constraints make the procedure somewhat conservative and enhancements are possible to make it more efficient or applicable to more geometries without compromising the safety of its operation. Such enhancements will need further research and study, and in some cases will require additional prototyping and simulations to determine their viability. We recommend that areas of possible enhancements such as those listed below be considered:

1. DCIAs for non-precision approaches -- develop procedures for other than straight-in precision approaches such as Instrument Landing System (ILS) or Microwave Landing System (MLS) approaches

2. Site-specific variable and asymmetric stagger values -- develop procedures that do not assume that all stagger distances are the same

3. Speed difference stagger values -- develop procedures that are based on ground speeds rather than airspeeds

4. Turning missed approaches -- develop procedures which do not constrain the DCIA procedure to require published straight-out missed approaches

5. Goal-based procedure -- develop a procedure that would allow the controller to adjust the stagger to account for differences in aircraft speed and winds and still meet the safety goals

6. Cockpit traffic display -- develop a procedure that would take advantage of self-separation provided by the pilot using a cockpit traffic display

7. Risk analysis -- develop a procedure which is based on the experience of DCIAs to relax the extremely conservative nature of the procedures described in this analysis

ACKNOWLEDGMENTS

The authors of this paper wish to thanks all those who contributed to the Dependent Converging Instrument Approach (DCIA) procedure. Those contributions eventually made it back into the analysis reported in this paper. In particular we would like to thank Dick Danz, formerly of Air Traffic Procedures and currently in the Capacity Office, for providing guidance during the initial stages of this analysis. Larry Paschich, also formerly of Air Traffic Procedures, provided the follow through to integrate the results of this analysis with the DCIA procedure order. We would also like to thank Spyder Thomas of Flight Standards for keeping us ever mindful of the user and safety perspective of this problem. Pati Otey of Air Traffic Operations added the controllers' perspective to our analysis for which we are grateful. To Janis Hooten of the Terminal ATC Automation (TATCA) Program Office and Mike Gough of Air Traffic Requirements we extend our thanks for coordinating the process of getting people together to discuss and resolve the issues and to move forward toward the DCIA order.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

When an airport experiences low ceiling or visibility conditions the arrival capacity of the airport is significantly reduced. This is particularly true at airports that use both their main runway and their crosswind runway in Visual Meteorological Conditions (VMC). For these airports the capacity is effectively reduced to that of a single runway operation in Instrument Meteorological Conditions (IMC). The consequence of this is an increase in air traffic delays.

In 1986 the Federal Aviation Administration (FAA) issued Order 7110.98 (FAA, 1986) that instituted Simultaneous Converging Instrument Approaches (SCIA). That order allows airports with converging runways to conduct operations to both runways in IMC provided certain constraints are satisfied. The procedure provides for the safety of the simultaneous operations with turning missed approaches and requires that missed approach points be moved so that they are separated by at least 3 nmi and the associated Terminal Instrument Procedures (TERPS) surfaces do not overlap. Because of these requirements, the minima for SCIAs tend to be quite high because the protection areas cannot overlap. The order also limits the operations to a minimum of 700 feet ceiling and 2 mile visibility for intersecting runway geometries. To date only four airports (Philadelphia, Dallas-Ft. Worth, Denver, and Washington Dulles) have utilized the provision of this order to reduce the minima to which they may use their converging or intersecting runways.

In the 1980s another concept for conducting approaches to converging runways was proposed (Newman et al, 1981, Mundra, 1987, and Lisker, 1988). In its final version, this procedure (Mundra and Danz, 1990) called for coordinating the approaches to the two runways such that a stagger between the aircraft[1] is maintained. This stagger would insure that if both aircraft had to miss their approaches, separation between them would be guaranteed even at the intersection of their flight paths. This procedure, which is named the Dependent Converging Instrument Approach (DCIA), is predicated on protecting against straight out missed approaches, and the minimum required stagger distance is set accordingly.

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1 A stagger between aircraft is the difference between the distance of one aircraft from the runway centerline intersection point and the distance of the other aircraft from the runway centerline intersection point.

Experience in the laboratory has shown (Mundra et al, 1989) that setting up and maintaining such a stagger is a skill that is difficult for controllers to apply consistently. Therefore an automation aid to assist controllers in achieving the required stagger was proposed (Mundra, 1988). This aid has become known as the Converging Runway Display Aid (CRDA). The aid can be described with reference to figure 1-1. For every Aircraft A on approach to one runway (R1) there is a *ghost* target GA displayed along the other approach path (P2) for converging Runway R2. The distances of the ghost target GA and the real target A from the point of intersection of the two runways or their extended centerlines are equal. The display position of the ghost target is updated every scan along with the update of the real target. Aircraft B is the trailing aircraft on the converging approach. The controller is required to establish a spacing between the ghost target GA and Aircraft B. Providing such spacing between a real aircraft and a ghost target results in assuring the required stagger between the real aircraft. The vectoring of an aircraft to follow another target on a radar scope is a controller skill that is highly developed.

The results of laboratory simulations with FAA controllers showed that controllers were able to use ghost targets for staggering aircraft on converging approaches (Mundra, 1989). Additional simulations with FAA controllers showed that not only was the staggering feasible but it could also lead to an Instrument Meteorological Condition (IMC) arrival capacity increase of over 20 percent (Barker, 1990).

In January 1990, the FAA's Terminal ATC Automation (TATCA) Program and the FAA's Air Traffic Service started evaluating DCIAs supported by CRDA at St. Louis-Lambert International Airport. A special software modification (or "patch") was specified for the ARTS IIIA computer at St. Louis to display "ghost targets" on the controller displays (Feldman, 1990) and was coded at the FAA Technical Center (FAATC). The evaluation was conducted according to an evaluation plan that called for operations, first in VMC, followed by operations in IMC (Gilligan, 1991). Prior to the operations in IMC, a computer simulation of consecutive missed approaches to St. Louis' runways 24 and 30R was run and the results showed that the stagger of 2 nmi behind a non-heavy aircraft and 5 nmi behind a heavy aircraft would produce acceptable separations at the intersection (Barker, 1992) as long as aircraft approaching slower than 100 kts were restricted to runway 24. This simulation was followed by a successful demonstration in July 1991 at St. Louis using real aircraft. After coordination with the user community, the FAA issued an Air Traffic authorization (a "waiver") to St. Louis to conduct DCIAs to its runways 30R and 24 in IMC (FAA, 1991). This authorization established the minimum stagger values and restrictions that St. Louis must use in order to conduct DCIAs to its runways 30R and 24. This authorization was issued only for runways 30R and 24 at St. Louis and was based on an analysis and simulation of that specific geometry.

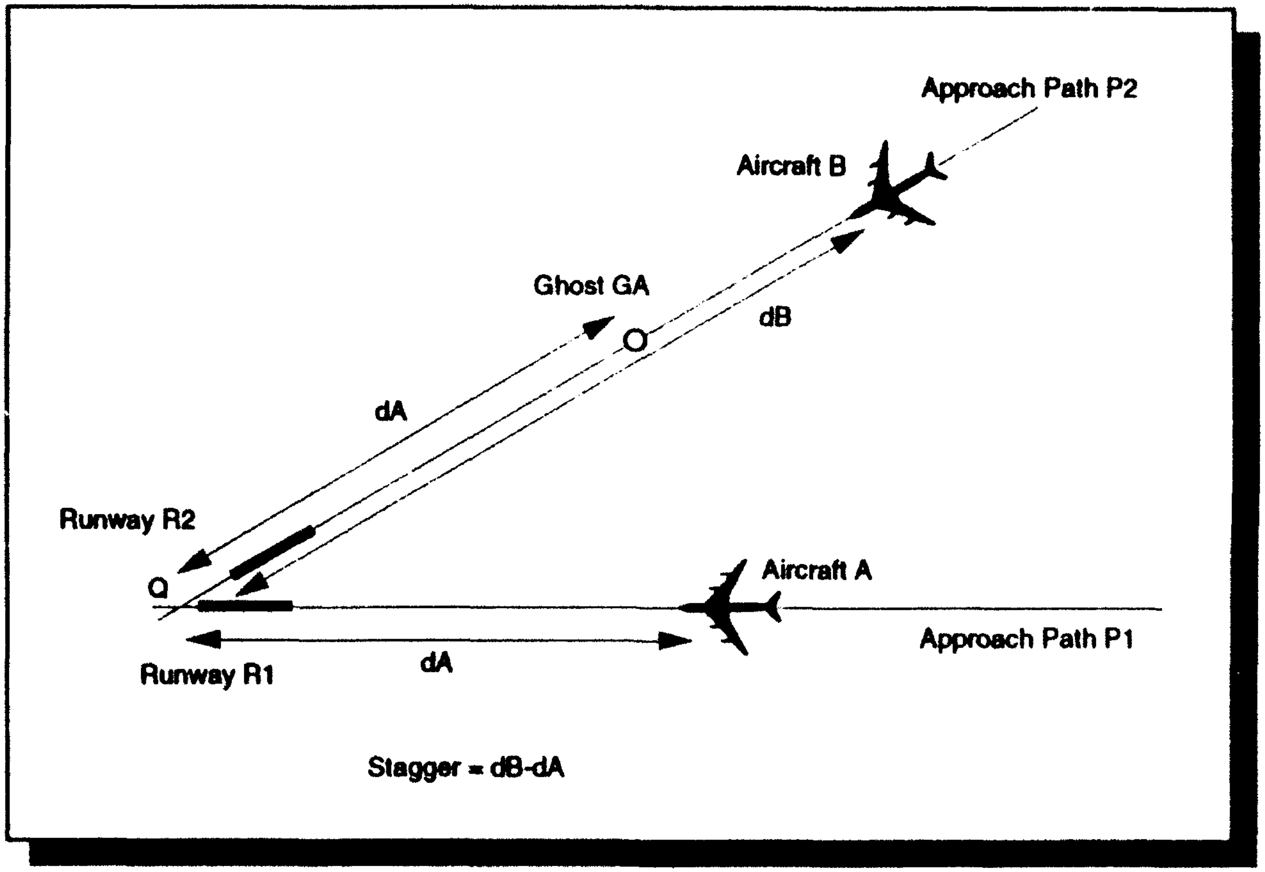

Figure 1-1. The Converging Runway Display Aid Concept

The evaluation at St. Louis was successfully completed in the spring of 1992 (Gilligan, 1992). Activities are currently underway to implement the CRDA automation nationally (Feldman, 1992). At least 20 of the top 100 airports in the United States have configurations and instrumentation that would enable them to take advantage of the DCIA procedure. An important element of this implementation process is the development of a DCIA procedure applicable to all eligible airports.

1.2 PURPOSE

The purpose of this paper is to develop a DCIA procedure applicable to any runway geometry. The procedure is defined and modeled to capture its safety-critical aspects. From this analysis recommendations are made concerning the stagger values and other factors relevant to applying this procedure safely to any runway geometry.

1.3 SCOPE

This paper discusses the procedural and safety aspects of the DCIA procedure rather than issues pertaining to automating the CRDA. The analysis presented in this paper deals with the DCIA procedure as it applies to any runway configuration in general. Worst case considerations are used as the basis of this general analysis. The analysis results in a look-up table such that the DCIA procedure for any given runway configuration can be determined from its geometry. An example of applying this table to a number of candidate airports is included. Finally, some specific examples are also provided to illustrate the point that a more specific analysis for individual airports can help reduce certain restrictions otherwise necessary in the general procedure.

1.4 AUDIENCE

It is assumed that the reader of this paper is knowledgeable about ATC in general and terminal area operations in particular. The information in this paper is developed for the procedure development organization in the FAA Headquarters as well as for use as reference material by the planning and procedures staffs at the facilities.

SECTION 2

ATC BASIS OF THE DEPENDENT CONVERGING INSTRUMENT APPROACH PROCEDURE

2.1 BACKGROUND AND PRINCIPLES

Newman, et al. (1981), Mundra (1987), and Lisker (1988) describe early studies relevant to the DCIA concept. Mundra and Danz (1990) describe the basic form of this procedure used for developing the authorization for the DCIA evaluation conducted at St. Louis from 1990 to 1992. Minor modifications to the procedure as described by Mundra and Danz (1990) and the necessary additional analyses led to the authorization issued to St. Louis for operating DCIAs to its runways 30R and 24. A copy of this authorization is included .n appendix F. The assumptions used to develop this authorization also form the basis for the analysis presented in this report, which addresses the development of a DCIA procedure applicable to any runway geometry.

The basic principle behind DCIAs is to coordinate arrivals on converging approaches such that the two aircraft may approach the runways with a certain amount of stagger. In the unlikely event that the aircraft on the two approaches should both conduct missed approaches, the stagger provided on approach is designed to be such as to guarantee that the aircraft will be separated during their missed approach without requiring any further intervention by the controller. The procedure thus guarantees safe passage even in the event of a radio failure and/or a radar failure.

The experience with SCIAs has indicated that in order to reduce the potential of pilot confusion, it is preferable to require one set of approach plates for a runway regardless of whether the runway is used singly or in a converging configuration. The experience with SCIAs has also indicated that whenever possible, straight out, rather than turning, missed approaches are desirable so that the aircraft will not be in a "belly up" configuration towards each other during their missed approaches. Straight out missed approaches also generate less workload for pilots, and inherently provide greater protection against late missed approaches. Finally, it should be noted that even when the published procedure is a turning missed approach, busy Terminal Radar Approach Control facilities (TRACONs) generally prefer to issue vectors for straight out missed approaches when the aircraft is in radar control.

DCIAs provide for aircraft separation during missed approach by:

1. Utilizing straight out published missed approaches

2. Assuring procedural (i.e., non-radar) separation between aircraft and protection from wake turbulence during missed approaches by requiring that there exist a certain stagger between arriving aircraft, and

3. Establishing values for the required stagger on approach to account for aircraft speed and performance variations, and the effects of different runway geometries and winds

In addition, the procedure addresses the questions of adequate separation on approach.

Figure 2-1 illustrates the DCIA concept. Thr_A and Thr_B are the runway thresholds for runways A and B, respectively. When an aircraft AC1 reaches Thr_A, the next aircraft approaching runway B is required to be a certain stagger distance behind on its approach. When an aircraft approaching runway B is the lead aircraft, the next aircraft approaching runway A is similarly required to be staggered by a specific amount. Straight out missed approaches are used. If both aircraft should conduct missed approaches, their flight paths would cross at point P where the runway centerlines or their extensions meet. Point P is therefore the reference point with respect to which protection must be provided. D1 and D2 are distances of AC1 and AC2 from point P. The stagger distance between the two aircraft is defined as (D2-D1). The DCIA procedure establishes the minimum required values for the stagger such that in all cases of runway lengths, included angles between the runways, individual aircraft speed differences, aircraft types and winds (1) the two aircraft will be adequately separated both on approach and missed approach, and (2) the trailing aircraft will be provided adequate wake vortex separation from the preceding aircraft when wake vortex is a factor.

The minimum stagger separation is required to be satisfied when the leading aircraft reaches its runway threshold.[1]

2.2 ATC BASIS

The DCIA procedure largely utilizes provisions already contained in the FAA Air Traffic Control Order 7110.65F (FAA, 1991) to develop requirements for the safe conduct of the

1 It should be noted that Mundra and Danz (1990) describe the DCIA concept with respect to missed approach points, i.e., require that the stagger be established at the missed approach point. Most other terminal separation standards are, however, enforced at the threshold. It was therefore determined by the FAA that the stagger for DCIAs be required at the threshold rather than at the missed approach point of the leading aircraft.

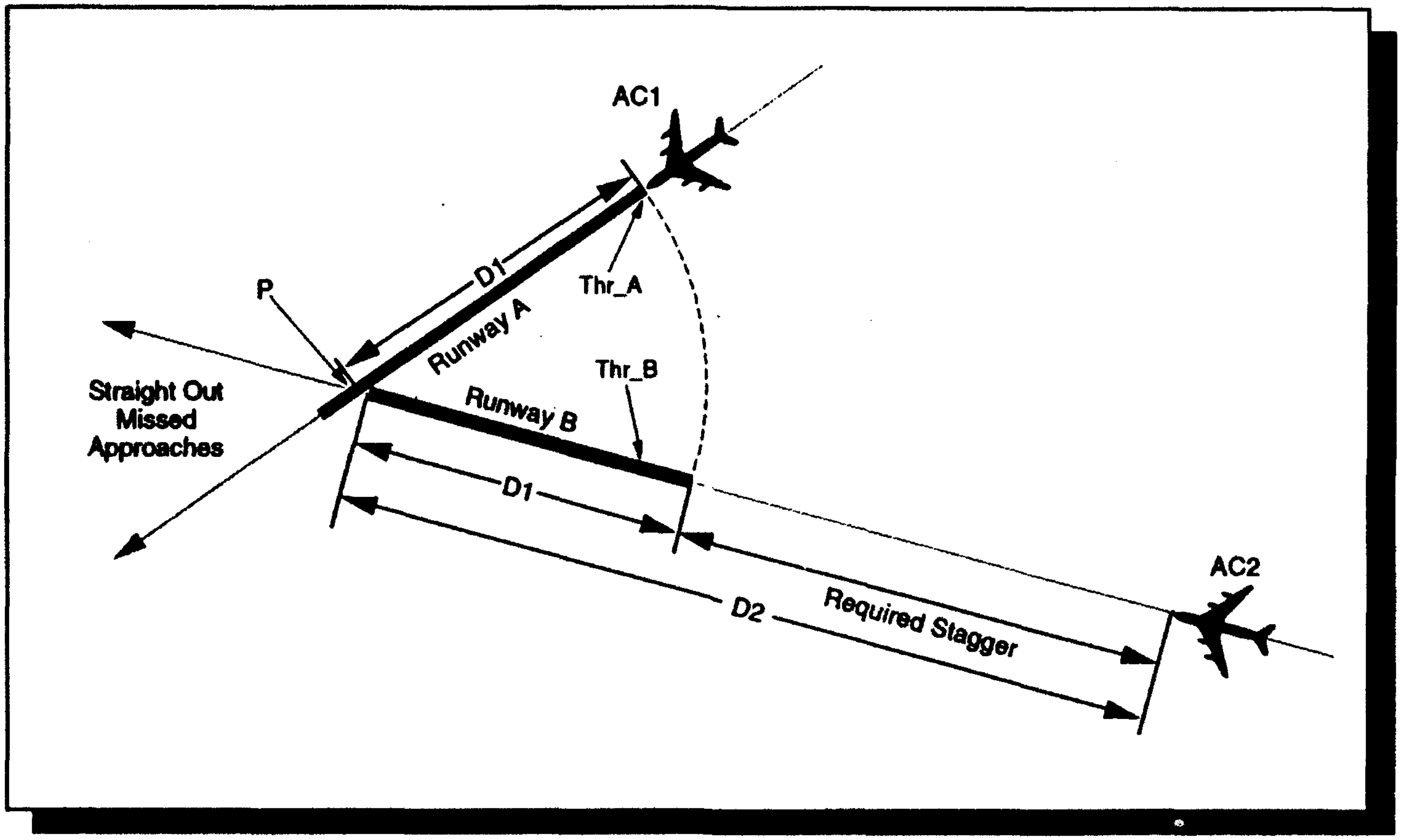

Figure 2-1. Dependent Converging Instrument Approaches

converging approaches envisioned in DCIA. In essence, the DCIA procedure utilizes radar control procedures to achieve the necessary stagger on approach and assures adequate separation by enforcing non-radar separation standards when radar contact is lost during a simultaneous missed approach.

The following paragraphs of FAA Order 7110.65F form the basis for this procedure:

Paragraph 3-91 Touch and go or stop and go or low approach
Paragraphs 3-108 and 3-123 Intersecting Runway separation
Paragraph 6-10 Minima on diverging courses
Paragraph 6-64 Interval Minima

The following paragraphs are also relevant:

Paragraph 5-114 Departure and arrival
Paragraph 3-84 Precision approach critical area
Paragraph 3-104, 3-127 Anticipating separation

And the following paragraph is affected

Paragraph 5-72

Paragraph 3-91 establishes that arrival aircraft that make a low approach, i.e., missed approach, are considered departures once they have crossed the landing threshold. Therefore, the procedures governing departure aircraft are used in determining the standards for DCIA.

Paragraph 3-108 states that controllers must separate departing aircraft from an aircraft using the intersecting runway, or non-intersecting runways when the flight paths intersect, by ensuring that a departure does not begin takeoff roll until the preceding non-heavy aircraft has departed and passed the intersection, or for aircraft taking off behind a heavy jet, two minutes after the heavy jet begins takeoff roll.

Figure 2-2 depicts the safety parameters of interest in greater detail. Let SEP be the distance between the aircraft when the leading aircraft is at the point of intersection (see figure 2-2B).

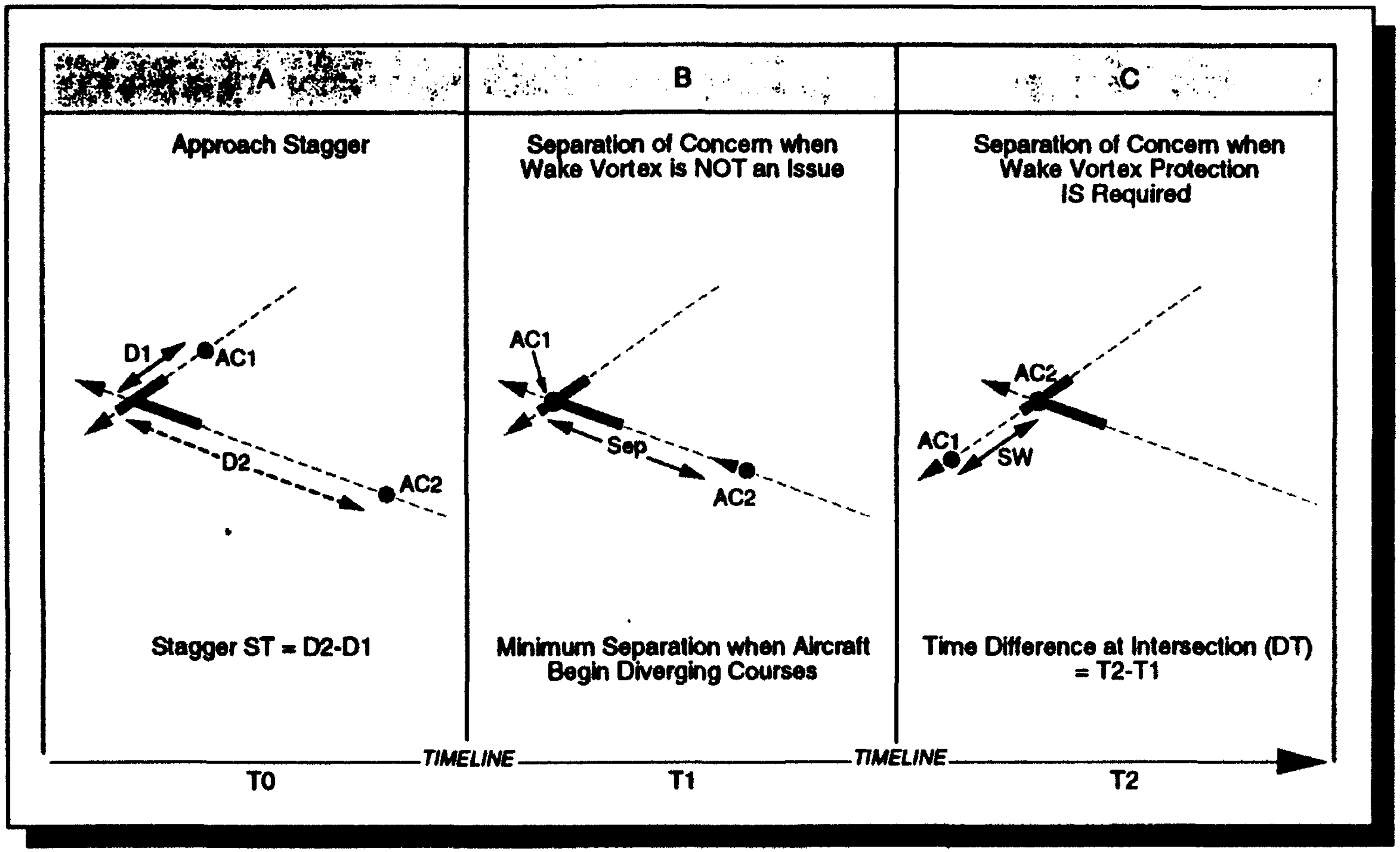

Figure 2-2. Parameters of Safety

SEP is then the minimum distance achieved between the aircraft in case of simultaneous/consecutive straight out missed approaches before they start diverging.[2]

At a point of time somewhat later than this, the trailing aircraft intercepts the path of the leading aircraft at the point of intersection of the runways or the extended centerlines. It is here that the trailing aircraft may experience the wake of the leading aircraft unless adequate separation is provided. The time elapsed since the leading aircraft passed the intersection is the parameter by which adequate wake turbulence protection may be measured.

When wake vortex protection is not an issue, i.e., when the leading aircraft is not heavy, the separation at the intersection, SEP, would have to be at least as much as the runway length of the aircraft on the trailing runway, as per a strict application of paragraphs 3-91 and 3-108. This, however, would lead to an inconsistent separation standard in case of consecutive missed approaches depending upon which aircraft were leading. When an aircraft on the runway with the longer distance to intersection were leading, a distance shorter than when it were trailing would be acceptable. A uniform minimum requirement of 1 nmi was therefore established by the FAA for the value of SEP for this analysis. The procedure thus requires a stagger distance such that in the event of simultaneous missed approaches when the leading aircraft is not heavy, the aircraft will still be separated by at least 1 nmi before they start diverging, even when there is a radio or radar failure.

The 2 minute rule in paragraph 3-108 establishes the point in time that a succeeding aircraft may be issued a take-off clearance after a leading heavy aircraft on an intersecting runway has begun its departure roll. The actual time elapsed between two departing aircraft crossing the same point, however, depends upon the runway geometry. This is illustrated in figure 2-3. AC1, a heavy aircraft, is the first one cleared for take-off. AC2 is cleared to take-off 2 minutes after AC1 begins its take-off roll. Suppose that Ttor is the time taken by aircraft AC2 to begin its take-off roll after a take-off clearance has been issued to it; and suppose that Tr1 and Tr2 are the times taken by AC1 and AC2 to travel from their respective runway thresholds where they start their take-off rolls, to the intersection point P. The actual time elapsed, DT, between when aircraft AC2 and AC1 cross the intersection point, P, is (2 minutes+Ttor-Tr1+Tr2). Clearly, if Runway 1 is significantly longer than Runway 2, then DT may be less than 2 minutes. In other words, the "2 minute rule" of paragraph 3-108

2 Diverging takes place after the first aircraft passes the intersection in front of the second aircraft. The separation between the aircraft can still decrease if the trailing aircraft is faster, but the situation is considered to be safe because the aircraft are now on diverging courses and the second aircraft will pass in back of the first aircraft.

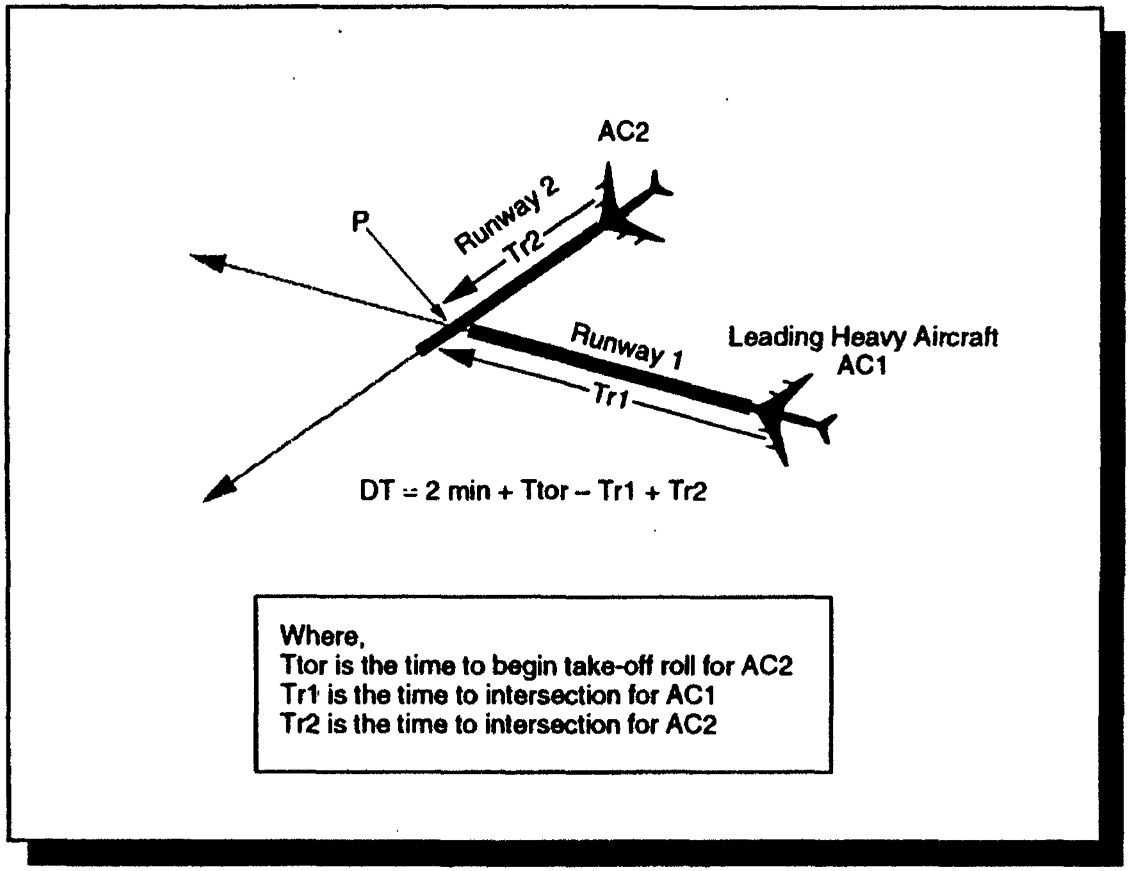

Figure 2-3. Time Difference Between Successive Departures when Departure Paths Intersect

provides safe separation behind heavies in the current system even when the actual time to cross the flight path of the leading heavy aircraft is less than 2 minutes.

An effort was made to determine representative values of actual flight path crossing times behind heavy aircraft observed in the system today. Appendix D documents data collected at St. Louis for this purpose. It was observed that in implementing the current wake vortex separation standards for aircraft in trail, a succeeding aircraft passed a point in space that a heavy aircraft had crossed 76 seconds after the heavy aircraft. It is generally believed that the wake encountered in crossing encounters is less severe than that encountered in-trail. In the interest of conservatism, however, it was established by the FAA for this analysis that a minimum of 76 seconds elapsed time (DT in figure 2-3) would be required between aircraft on converging missed approaches when the leading aircraft is heavy.

Paragraph 6-10c(2), dealing with the initial separation ot successive departing aircraft, specifies non-radar separation standards for intersecting runways and states that controllers may authorize takeoff of succeeding aircraft when the preceding aircraft has passed the point of runway intersection, that the runways diverge by 30 degrees or more, and that the departure courses diverge by at least 45 degrees. This established the requirement in DCIAs for runways to have a minimum included angle of 30 degrees and missed approach procedures for the converging approaches have at least 45 degrees course divergence.

An upper limit of angle between runways of 120 degrees was established. This provided a range (90 degrees) of angles between runways for which the DCIA procedure could be used without the encounter geometry becoming nearly "head-on".

Paragraph 3-123 establishes the requirements for separation on intersecting runways. Those requirements address runway separation in general, and apply to VFR as well as IFR conditions. Thus, when dependent converging IFR approaches are in use for intersecting runways, paragraph 3-123 establishes the requirements that must be satisfied regarding runway separation. It establishes such standards as prohibiting an aircraft from crossing the threshold on one runway until an aircraft on the intersecting runway has passed the runway intersection, or taxied off the runway, or has completed the landing roll and will hold short of the intersection. In general, the staggering of aircraft on approach will aid the tower in satisfying the requirements of paragraph 3-123. If, however, a particular aircraft pair or a runway geometry should require additional stagger than that needed for the DCIA procedure in order to assure runway separation requirements of paragraph 3-123, the facility and the controller would be expected to implement the necessary adjustments.

It should be noted that the FAA is in the process of revising the provisions of paragraph 3-123, in particular the hold short requirements in IFR conditions. If and when such changes are implemented, the revised provisions would apply to the DCIA operation for intersecting runways.

The minimum allowable stagger distance was set at 2 nmi for this analysis. A 2 nmi stagger with respect to the intersection guarantees a minimum of 2 nmi separation-in-space for all applicable geometries for when the leading aircraft crosses its threshold. 2 nmi-in-space is the separation currently required for aircraft on straight-in precision approaches for parallel (dependent) operations. Although it could be argued that the aircraft in the dependent parallel operations are established on parallel courses when a 2 nmi in-space separation is provided, the exposure to this minimum spacing is over a long distance and time, typically 7 to 15 nmi on final, depending on the airport. In contrast, the minimum in-space separation between aircraft on converging approaches will only be for a short time at the point when the leading aircraft reaches its threshold.

Figure 2-4 shows the dependence of the in-space separation between aircraft on a converging runway approaches on the included angle between the runways and the distance from the intersection of the leading aircraft. For a 60 degree included angle between the runways and the leading aircraft at its runway threshold (where the stagger is enforced) 1.5 nmi from the intersection, the in-space separation between the aircraft when they are staggered by 2 nmi is more than 3 nmi. In effect, then, the 2 nmi minimum stagger requirement for dependent parallel operations establishes that the separation-in-space between airborne aircraft on converging approaches never be less than 2 nmi. This requirement which will appear in the national DCIA order will effectively modify the radar separation requirements of paragraph 5-72 for aircraft on precision converging approaches in the same way that paragraph 5-125 modifies paragraph 5-72 for aircraft conducting dependent parallel operations.

Figure 2-2c also shows the distance SW between the aircraft when the trailing aircraft reaches the intersection.[3] If the aircraft speeds were equal and remained unchanged during their missed approaches, the distance SEP and SW would both equal the stagger. Due to differences between aircraft approach speeds and speed changes during missed approach, however, the separations achieved (SEP and SW) would be somewhat different from the stagger provided at the threshold. Both the ground speeds of the individual aircraft during the encounter and the distances traveled during the encounter affect the degree to which the achieved separation at the intersection is different from the stagger separation provided at the

3 The distance SW between the aircraft when the trailing aircraft reaches the intersection is also another possible parameter by which adequate wake vortex protection may be measured.

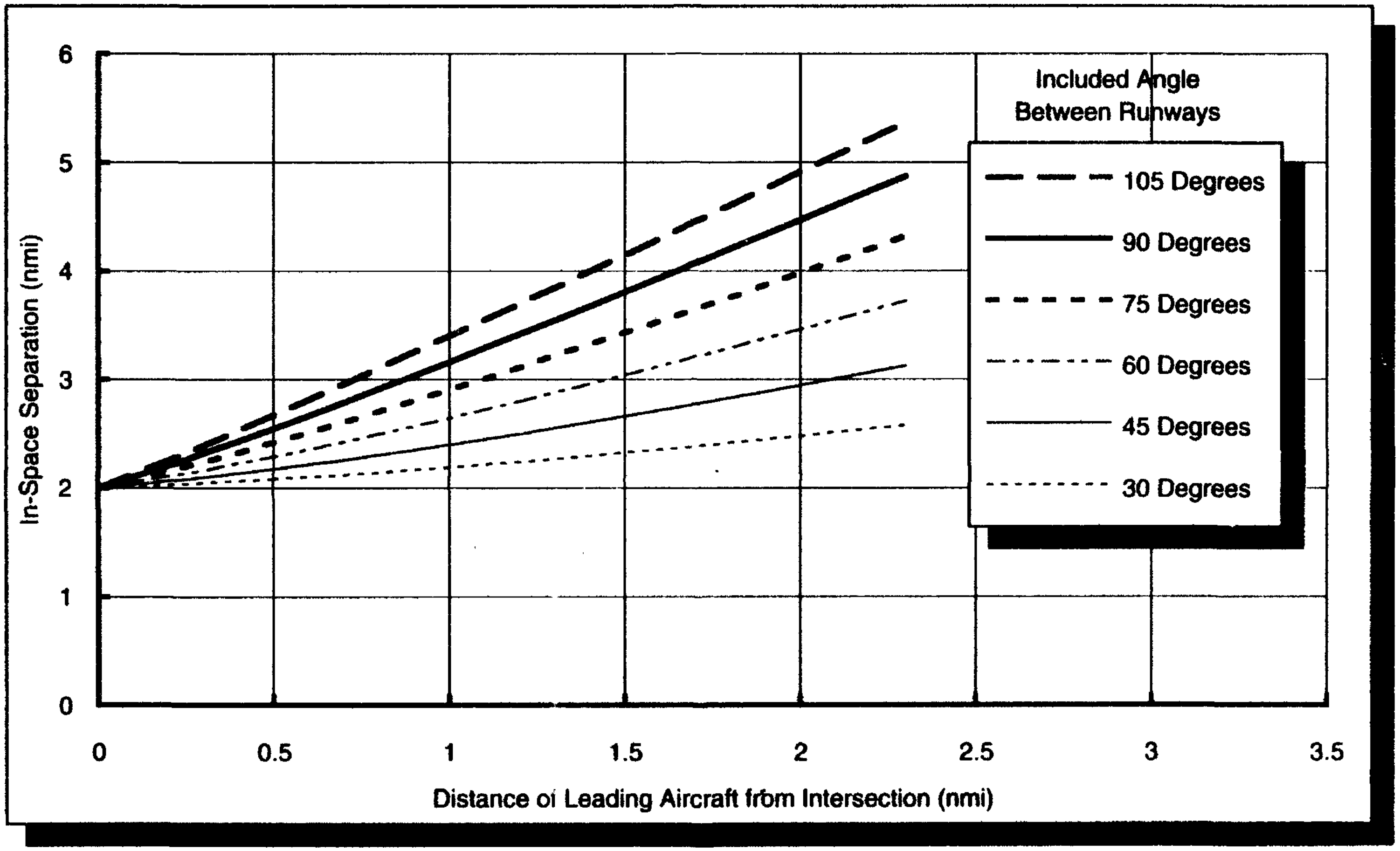

Figure 2-4. Distance in Space for Aircraft on Staggered Converging Approches with a 2 nmi Stagger

threshold. Therefore, individual aircraft approach and missed approach speeds, winds, and distances of the threshold to the intersection are the primary parameters affecting the stagger required for adequate separation.

Paragraph 6-64 in FAA Order 7110.65F describes how controllers are required to make spacing adjustments to take into account relative speeds of aircraft and existing weather conditions to satisfy the interval minima for timed approaches. Controllers could similarly be expected to adjust the stagger required for DCIA approaches such that the separation at the intersection in case of consecutive missed approaches would be 1 nmi when the leading aircraft is non-heavy, and 2 minutes when the leading aircraft is heavy. Thus, if the two converging aircraft were approaching the airport at compatible final approach speeds and winds were calm, then a 2 nmi stagger on approach would be expected to provide about a 2 nmi separation at the intersection in case of simultaneous/consecutive missed approaches. On the other hand, if the two aircraft had approach speeds differing by 60 kts (say the leading aircraft was flying at 90 kts and the trailing aircraft at 150 kts, respectively), the winds were calm, and the runways were both 1 nmi long to the intersection, then in the event of a consecutive missed approach, depending upon the missed approach performance, over one-half nmi of the stagger on approach may be lost by the time the lead aircraft reaches the intersection, resulting in a little over 1 nmi separation at the intersection.

Since missed approaches are rare events, it was determined that more explicit guidance be made available to controllers about the stagger required on approach such that if satisfied, then even in the worst cases of winds and aircraft speed differentials, a simultaneous unavailability of either radar or radio, and simultaneous (i.e, consecutive) missed approaches, the aircraft would still be safely separated at the intersection.

This paper documents the analysis and recommendations regarding the stagger values required at the threshold to satisfy the separation requirements established above. The recommended stagger distances on approach are desired in a form such that, given typical aircraft arrival streams, the TRACON and tower controllers would be able to determine the spacing to be provided.

The procedure analyzed here assumes straight-in precision approaches (i.e., ILS or MLS) with or without an operating glide slope. Additional analysis would be required to extend the procedure for other non-precision approaches or to angled approaches.

2.3 MISCELLANEOUS

It should be noted that paragraph 5-114 establishes rules for radar separation of arrivals and departures.

Paragraph 3-84 restricts an aircraft to be outside the outer marker when another aircraft is in an ILS critical area. If a converging configuration creates a geometry such that an aircraft on one approach may, upon landing, pass through the ILS critical area of the other approach, the DCIA operation for that configuration would be limited to the appropriate higher minima of 800 ft ceiling and/or 2 mi visibility.

Paragraphs 3-104 and 3-127 (anticipating separation) enable controllers to issue clearances to departing and landing aircraft when reasonable assurance exists that prescribed separation will exist when an aircraft start its take off roll or crosses the runway threshold. This enables the establishing of stagger in the approach stream and clearing aircraft to land in order that required separation will exist either in case of a consecutive miss or when the aircraft land.

SECTION 3

MODEL OF THE DEPENDENT CONVERGING INSTRUMENT APPROACH PROCEDURE

3.1 GENERAL DESCRIPTION OF THE DCIA MODEL

The model used to define the DCIA procedure is based on the dual missed approach model and simulation developed for St. Louis (Barker, 1992). The DCIA model extracts the important features of the St. Louis model and generalizes them for application to other geometries.

3.1.1 Overview of the Model

It was determined in the St. Louis simulation that the primary factors of the final separation of two aircraft executing missed approaches were: (1) the initial stagger, i.e., the differential distance to intersection; (2) the ground speed differential of the two aircraft; (3) the speed of the leading aircraft[1]; (4) the relative accelerations of the two aircraft; and (5) the distances from runway thresholds to the intersection of the runways (or their extended centerlines).

Wind is included in the model as a worst case condition. The wind components that produce the minimum separation at the intersection, as determined by the allowable range of included angles between the runways and the maximum allowable wind speeds, are always used in the analysis.

3.1.2 Aircraft Approach and Missed Approach Profiles

In the DCIA model the approach and miss profile of a given aircraft is considered in four phases: (1) an aircraft is assumed to cross the outer marker at a fixed nominal speed; (2) the aircraft begins a constant deceleration phase after crossing the outer marker and is assumed to reach its Final Approach Speed (FAS) after flying a given distance; (3) the aircraft maintains its FAS until it reaches its Missed Approach Point (MAP); (4) at the MAP the aircraft enters a constant acceleration phase, the actual acceleration being dependent on aircraft type. The points along the approach path at which these events happen is shown in

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1 The speed of the leading aircraft is distingushed from the speed differential because, as it turns out, a very slow leading aircraft allows more time for a given stagger to degrade. In other words, on a given geometry, the speed differential is more important for scenarios involving slow leading aircraft.

figure 3-1. The procedure specifies that the aircraft fly the heading of the runway after executing the miss. Altitude is not modeled explictly in the DCIA model although the acceleration values have been bounded based on the acceleration profiles discussed below which are altitude dependent. The maximum speed in the terminal area of 250 kts was observed in the model.

3.2 PARAMETER RANGES AND PROCEDURE RESTRICTIONS

The FAA's Air Traffic and Flight Standards organizations have established the parameter ranges and procedure restrictions listed in table 3-1 as those that provide adequate safety and reflect the expected range of operational and environmental conditions.

The rationale for these values is as follows:

Minimum separation at intersection. When the leading aircraft is non-heavy a value of 1 nmi will be used. This is a distance that those representing Air Traffic and Flight Standards felt comfortable with. It represents a value that is larger than the minimum separation criteria being used on parallel runways (because the aircraft are being placed on a converging course on purpose) while being smaller than the 2.5 nmi terminal area minimum separation and the 2 nmi parallel approach dependent minimum separation.[2]

When the leading aircraft is heavy a value of 76 seconds will be used. This value was arrived at as a consequence of the current rules in the controller's handbook (FAA, 1991). Those rules tate that takeoff clearance to the following aircraft should not be issued until 2 minutes after the heavy jet *begins* takeoff roll (FAA, 1991, paragraph 3-106f). The same reference also states that departing aircraft operaing directly behind, or directly behind and less than 1,000 feet below a heavy aircraft may be separated by 5 nmi (FAA, 1991, paragraphs 5-72d and 3-106e). The implication of these rules is that the separation following a heavy when both are airborne over the same point is not necessarily 2 minutes. In fact, data was taken at St. Louis where a heavy departure was followed by a non-heavy departure off the

2 Appendix D discusses this in more detail.

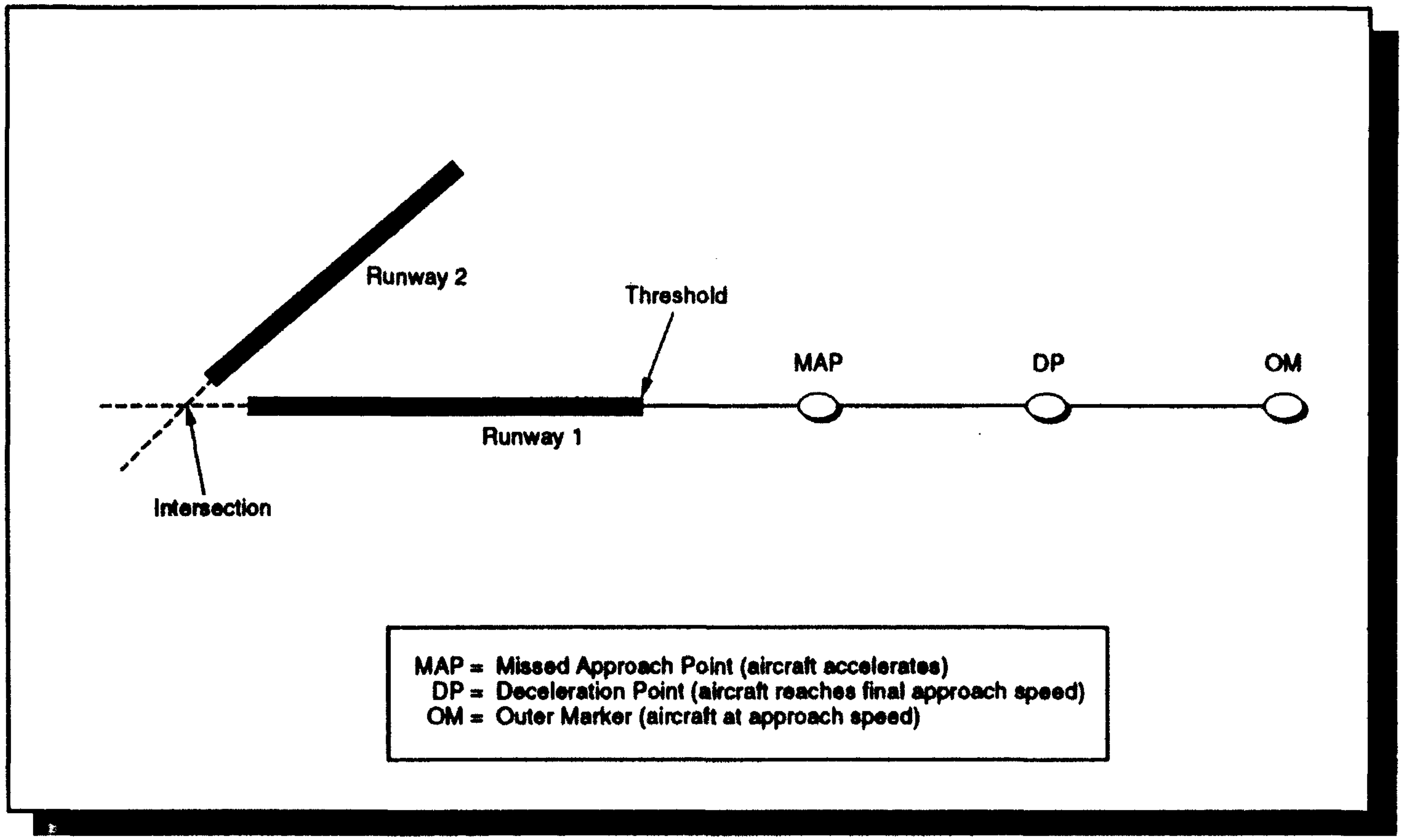

Figure 3-1. Missed Approach Geometry

Table 3-1. Parameters and Restrictions for the Analysis of DCIAs

Parameter	Values
Minimum separation at intersection	1 nmi for non-heavy leading aircraft 76 seconds for heavy leading aircraft
Included angles between the runways	30 degrees minimum 120 degree maximum
Approach airspeed at Outer Marker	174 kts
Final approach airspeeds	80 kts minimum 170 kts maximum 10 kt increments
Missed approach accelerations	Equivalent to the maximum effective acceleration to the intersection for the aircraft using St. Louis with a maximum speed of 250 kts (See appendix B)
Distance from runway threshold to intersection	0 feet minimum 27,300 feet maximum 100 foot increments
Winds	30 kts maximum 15 kts maximum crosswind 5 kts maximum tailwind
Forms of restrictions[3]	• Restrict x kt or less aircraft to runway with shorter threshold to intersection distance ($80 \leq x \leq 120$) • Except y kt or greater aircraft ($y \geq 160$) • Except s kt or less aircraft ($s \leq 90$) • Do not pair z kt or less aircraft leading with y kt or greater aircraft trailing ($z \leq 110$) • Restrict and do not pair • Restrict and except • Except and do not pair
Decision Heights	250, 500 and 700 feet
Stagger	2, 2.5 and 3 nmi for non-heavy leading aircraft 5 and 6 nmi for heavy leading aircraft

3 A more complete discussion of these restrictions can be found in section 3.2.

same runway. The minimum airborne separation was slgihtly greater than 5 nmi and the time separation between the aircraft over a point where both aircraft were airborne was 76 seconds.[4]

Included angles between the runways. The 30 degree value corresponds to the missed approach course separation (FAA, 1991, paragraph 5-115). The 120 degree value was established by the representatives of Air Traffic and Flight Standards.

Approach airspeed at the outer marker. The range of airspeeds at the outer marker is typically about 170 to 180 kts. 174 kts was chosen to be in the middle of this range and to be such that the jet fighters at the high end of their speed range would not have to slow down to reach their final approach airspeed. Approach airspeeds for general aviation aircraft are unnecessary for this analysis because the stagger distance is always determined by the faster trailing aircraft.

Final approach airspeeds. The range of 80 to 170 kts indicated airspeed cover the approach speeds of the aircraft at commercial airports. The approach speeds are considered in 10 kt increments. This means that aircraft with a nominal final approach speed of 80 kts would be those with speeds from 75 kts through 84 kts. When the aircraft are analyzed in pairs, the leading aircraft are assigned the final approach speed value at the low end of the 10 kt range while the trailing aircraft are assigned the final approach speed value at the high end of the range. This is another feature of the analysis that is consistent with the worst case aspect of this analysis

Missed approach accelerations. The sample of aircraft used in the investigation to support the operations in St. Louis was also used to determine an envelope of missed approach accelerations. These acceleration envelopes are divided into three categories: heavy, fighter jets, and other. The general aviation aircraft are part of the "other" category. Appendix B addresses the modeling of the accelerations in more detail.

Distance from runway threshold to intersection. The distance from the runway threshold to the intersection of the centerlines of the two runways ranges from 0 feet to 27,300 feet. This range covers all of the airports in the top 100 airports in the country that have been identified as having DCIA application potential.

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4 The separation at the intersection is not expected to reach this minimum value with a significant probability as discussed in section 3.3.7.

Winds. The winds in this analysis will be no more than 30 kts, regardless of the direction. If the conditions are IMC and the wind is greater than 30 kts, there are probably instabilities in the atmosphere and the pilots will be reluctant to land. In addition, there are crosswind and tailwind conditions beyond which the pilots will not land. The rule of thumb is 15 kts and 5 kts, respectively.

Forms of restrictions. In order to achieve the safety level (i.e., the proper separation at the intersection following a consecutive missed approach) for some runway configurations, it is necessary to limit the possibility that all aircraft be allowed to land on either runway. There are many ways to limit which aircraft can land on which runway in a safe manner. Of those ways, it was agreed by Air Traffic that the restrictions listed in table 3-1 are operationally feasible. In general, restricting aircraft below 120 kts to a particular runway is feasible because commercial jets tend to have final approach airspeeds of 120 kts or greater. The restriction, as stated in table 3-1, includes the 120 kt class of aircraft also.

To "except" an aircraft from this procedure means that when an aircraft with the indicated speed is included in an operation there must be a larger stagger. If the excepted aircraft is leading and is slower, a larger stagger behind this aircraft is required. If the excepted aircraft is trailing and is faster, a larger stagger in front of this aircraft is required. The fast aircraft to be excepted are those with final approach airspeeds of 160 kts or greater. These are usually the jet fighter aircraft and there will not be too many of these aircraft at the airports under consideration. The slow aircraft to be excepted are those with final approach airspeeds of 90 kts or less. These are general aviation aircraft and the impact of this restriction at a particular airport will depend on the equippage and population of general aviation aircraft using that airport. The relative abundance of general aviation aircraft is typically reduced during IMC.

Safety can be maintained for some runway configurations by not allowing aircraft with certain final approach airspeeds to be paired. It was agreed by Air Traffic that not pairing commuter and general aviation classes of aircraft (110 kts or less) with fighter jet aircraft (160 kts or greater) would probably not severely impact the operations at the airports under consideration. Even at that, if the faster aircraft were leading there would be no problem pairing the two aircraft.

Finally, applying the restrictions in a pairwise fashion (e.g., restrict and do not pair, restrict and except, except and do not pair) was also agreeable to Air Traffic.

Decision heights. The decision height has an impact on the separation at the intersection. In terms of the operation, if the glide slope were to go out, the decision

height would be higher. The decision heights at the airports of interest were reviewed and it turned out that they could be grouped into three groups: 250 feet or less, between 250 and 500 feet, and between 500 and 700 feet. For decisions greater than 700 feet other procedures such as SCIAs could be run and there would be no advantage to running a DCIA procedure.

Stagger values. The minimum stagger value of 2 nmi reflects the fact that in worst case situations the separation between the aircraft will degrade as the leading aircraft approaches the intersection. In order to insure at least 1 nmi at the intersection in the event of consecutive missed approaches, the 2 nmi stagger is reasonable. The increment of the stagger was set at 0.5 nmi. Any smaller interval was judged to be too small for the controller to perceive reliably with today's automation. The maximum stagger was set at 3 nmi. If the stagger were any larger, the capacity advantage of using converging approaches over using a single approach would be lost. For the heavy leading case, 5 and 6 nmi staggers are analogous to the separation rules behind heavies today.

3.3 DETAILED DESCRIPTION OF THE DCIA MODEL

The following sections give an overview of the particulars of the DCIA model. A mathematical treatment of the equations of motion that comprise the closed-form analytical model can be found in appendix A.

3.3.1 Initial Aircraft Positions

Without loss of generality, the DCIA model places the leading aircraft initially at its runway threshold. The initial placement of the trailing aircraft depends on the value of the stagger chosen for the scenario. For a given stagger value, the position of the trailing aircraft on its approach is uniquely determined. An example of initial aircraft positions with 2 nmi threshold stagger is shown in figure 3-2.

3.3.2 Duration of Scenario for Non-Heavy Leading Aircraft

Figure 2-2B depicts the separation of concern for the case of a non-heavy leading aircraft where the separation is measured when the leading aircraft reaches the intersection. The execution of the consecutive missed approach proceeds by first calculating the time required for the leading aircraft to reach the intersection. In the DCIA model the leader is assumed not to accelerate during the missed approach. This assumption is made in the spirit of conservatism. Therefore, the time for the leading aircraft to reach the intersection is simply

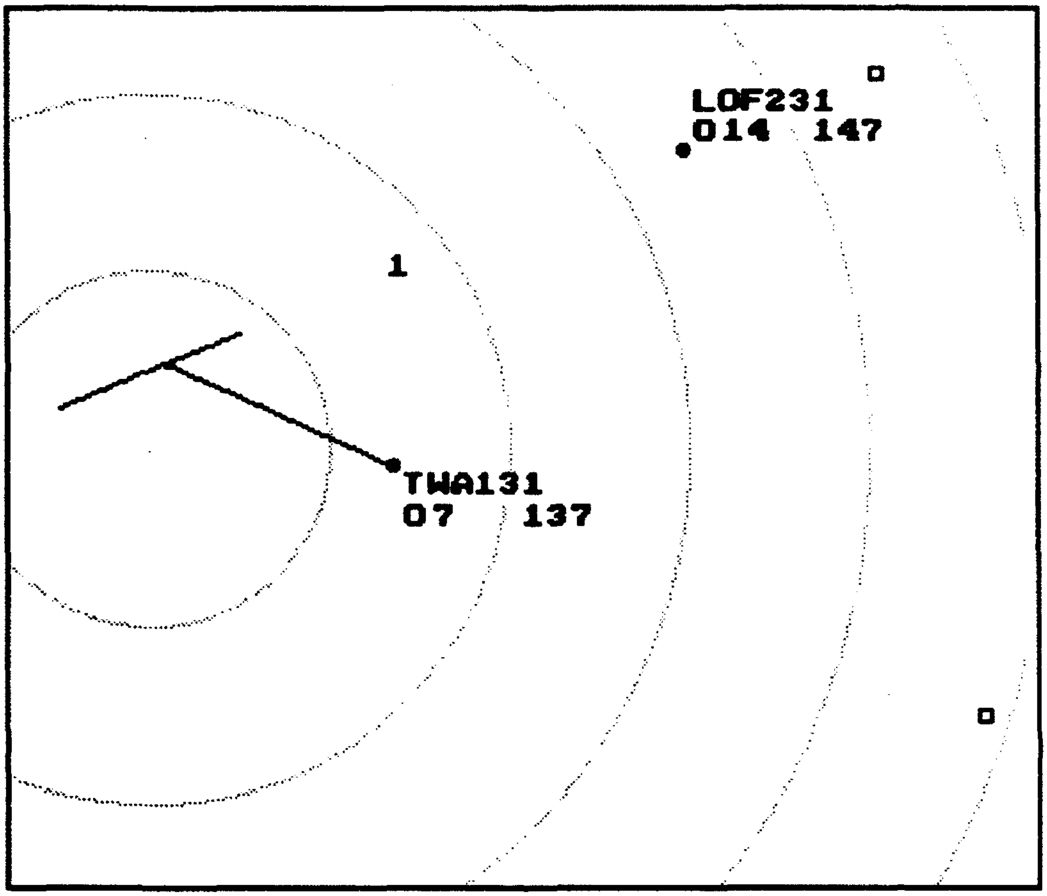

Figure 3-2. Example of Threshold Stagger

With the leading aircraft at threshold the position of the trailing aircraft is uniquely determined for a given stagger value. This illustration shows an aircraft (TWA131) at the threshold of St. Louis runway 30R, already executing a missed approach. The trailing aircraft (LOF231) is approaching runway 24 and is positioned 2 nmi behind the "ghost" of TWA131, indicated by the "1". In this case the trailing aircraft is inside of the outer marker (indicated by the small square) and not yet at the missed approach point for runway 24. The DCIA model carries the scenario forward from this point to determine the final separation at the intersection of the flight paths.

the distance from the threshold of the runway for the leading aircraft to the intersection of the flight paths divided by the final approach ground speed of the leading aircraft.

The trailing aircraft moves toward the intersection during this time interval. The scenario ends when the leader is at the intersection. The separation of interest is then simply the distance of the trailing aircraft from the intersection at the time when the leading aircraft is at the intersection.

3.3.3 Duration of Scenario for Heavy Leading Aircraft

In the case of a heavy leading aircraft the scenario does not end when the leading aircraft gets to the intersection. It is necessary to determine how long it will take the trailing aircraft to reach the intersection after the leading heavy aircraft passes through the intersection to determine the wake vortex avoidance separation time. See figure 2-2C. Therefore, after the leading aircraft reaches the intersection, the DCIA model "moves" the trailing aircraft to the intersection as a function of its approach and missed approach profile. The difference in the times that the leading and trailing aircraft cross the intersection is the separation of interest when the leading aircraft is a heavy. The dynamics of the trailing aircraft are considered below.

3.3.4 Movement of the Trailing Aircraft

The DCIA model is implemented as a closed form analytic solution. However, it is convenient to think of the aircraft as "moving through" its approach and subsequent missed approach. The following sections provide a description of the factors that influence the movement of the trailing aircraft.

3.3.4.1 The Initial State of the Trailing Aircraft

The initial position of the trailing aircraft is uniquely determined from geometrical considerations. Based on the intersection to threshold distances of both runways and the stagger distance the position of the trailing aircraft can be determined.

The speed and acceleration of the trailing aircraft at this point is important to the remainder of the scenario. There are four possibilities. Considering figure 3-1, the four possibilities depend on whether the initial position of the trailing aircraft is outside the outer marker (OM), between the deceleration point (DP) and OM, between the missed approach point (MAP) and DP, or inside the MAP. If the trailing aircraft is outside OM its speed is the approach speed and it is not accelerating. If the trailing aircraft is between OM and DP its speed is dependent on its position between DP and OM and it is decelerating at a rate that will cause it to reach its final approach speed at DP. Between MAP and DP the trailing

aircraft is at its final approach speed and it is not accelerating. Inside the MAP the aircraft is accelerating. In the DCIA model this acceleration is modeled as an instantaneous speed increase. The missed approach acceleration will be discussed further in section 3.2.4.4.

3.3.4.2 Deceleration of the Trailing Aircraft

If the initial position of the trailing aircraft is further from the intersection than the point DP, then the deceleration of the trailing aircraft must be considered. The deceleration from its approach airspeed to its final approach airspeed is modeled to begin after crossing the outer marker. A constant deceleration is assumed that requires the aircraft to fly 3 nmi to reach its final approach airspeed. Although aircraft decelerate differently, the fact that they are in a landing pattern will tend to moderate this variation. Most aircraft will reach their final approach airspeed about half way down the final approach course according to pilots and observations. Knowing the approach speed at the outer marker and the final approach speed 3 nmi from the outer mark the DCIA model determines the correct initial speed for the trailing aircraft.

3.3.4.3 Decision Height for the Trailing Aircraft

Three different decision heights are modeled for the miss of the trailing aircraft. They are 250 feet, 500 feet and 700 feet. The decision height is an important factor to model for the following reasons: if the decision height is increased, all other factors being equal, the trailing aircraft's missed approach would be initiated at a relatively higher speed and the trailing aircraft would accelerate sooner. All other factors being equal, a scenario in which the trailing aircraft executes a missed approach at a higher decision height would result in lower separation at the intersection.

3.3.4.4 Acceleration of the Trailing Aircraft

The trailing aircraft is modeled to begin a constant aircraft-dependent acceleration at its missed approach point. The acceleration is applied through the remainder of the scenario with a maximum speed of 250 kts.

When an aircraft accelerates on executing a missed approach, the object for the pilot is to change the aircraft from a landing configuration to a climb-out configuration. Based on the weight of the aircraft and other dynamic attributes of the aircraft, the achieved acceleration can vary. This range of accelerations is modeled as a factor increase in speed over the final approach speed. In other words, the acceleration is modeled as an instantaneous speed increase. The aircraft which were investigated in detail for the St. Louis analysis were placed in three categories based on their missed approach accelerations. The fighter jets are one category, the heavy jets are the second category and all others formed the third category.

Using a detailed model discussed in appendix B, a characterization of the acceleration as a factor increase in speed was developed. The factor increase in speed depends on the distance of the threshold to the runway intersection and the altitude at which the missed approach is executed. The results of this analysis are shown in figures 3-3, 3-4, and 3-5.

3.3.4.5 The Effect of Winds

The winds have a significant effect on the outcome of the separation at the intersection following consecutive missed approaches. It is noted that the minimum separation at the intersection depends on a number of factors such as speed differentials, accelerations, and distances to travel to the intersection. All other factors being the same, the minimum separation occurs when either there is a maximum differential wind condition (i.e., a high tail wind component on the trailing aircraft and a high headwind component on the leading aircraft) or there is the maximum headwind on the leading aircraft. The feasible conditions are contingent on the maximum tailwind, crosswind and absolute wind requirements. The analysis of the worst case wind conditions can be found in appendix C.

The results of the worst case wind conditions are shown in table 3-2. For any given runway configuration, as characterized by the included angle between the runways, there is a wind direction and magnitude that will yield the maximum differential wind. There is also a wind direction and magnitude that will yield the maximum headwind on the leading aircraft. One can notice from table 3-2 that the greatest maximum differential wind will occur when the included angle between the runways is about 110 degrees. The greatest maximum headwind on the leading aircraft will occur when the included angle is 30 degrees, the minimum included angle allowed.

The way in which this information was factored into the analysis to produce the worst case situation is as follows. The separation at the intersection following a consecutive missed approach was computed twice; once under the condition of a maximum headwind on the leading aircraft assuming a 30 degree included angle between the runways and again under the condition of a maximum differential wind assumming a 110 degree included angle between the runways. Then the minimum separation at the intersection was chosen as the worst case separation.

The implication of this method of analysis is that the dependence of the result on the included angle between the runways has been eliminated. However, it should be noted that in reality no given pair of runways can have both an included angle of 30 degrees and 110 degrees. Therefore, this analysis for airports in general will be conservative in that for a given airport with a given set of converging runways the actual separation at the intersection

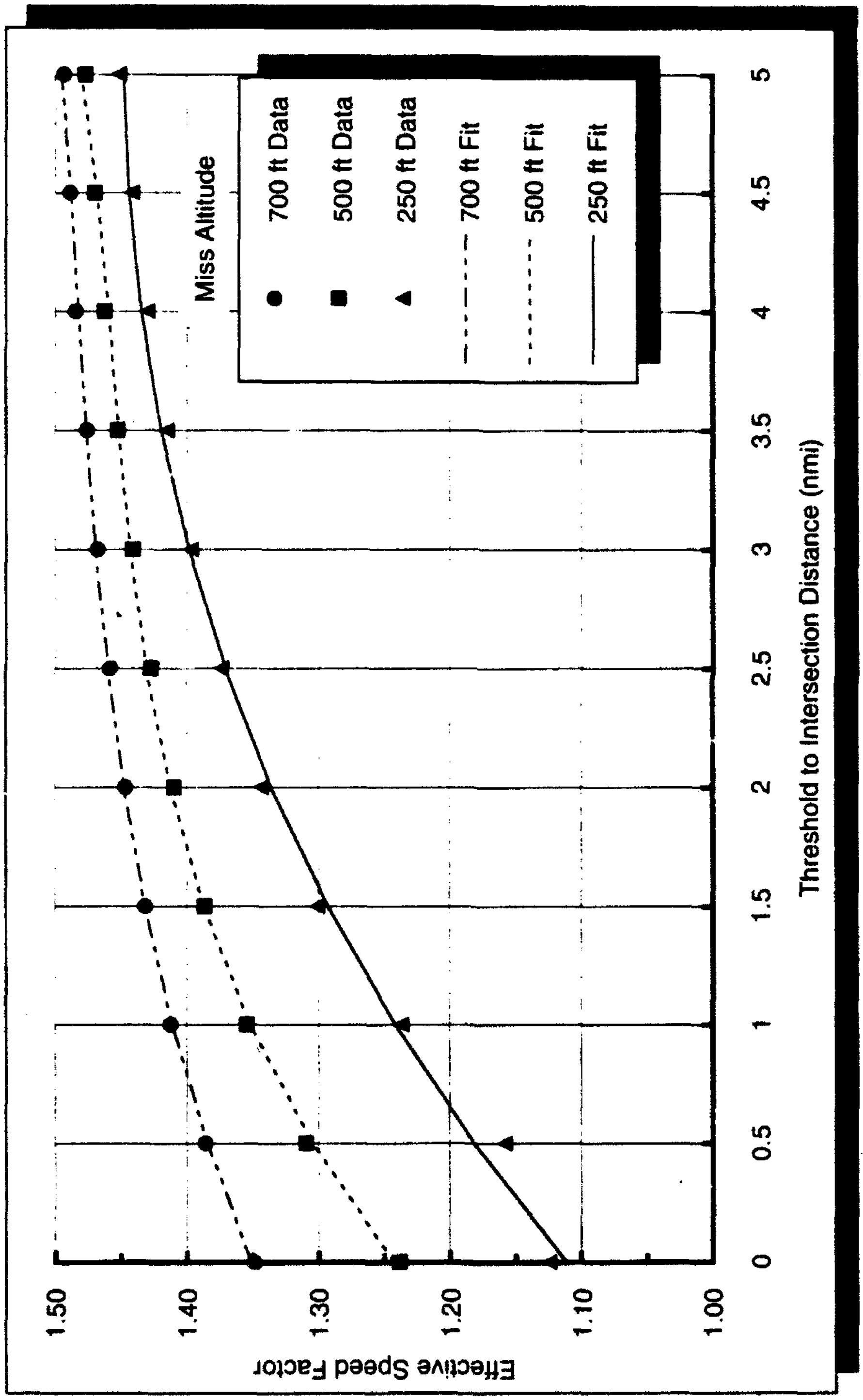

Figure 3-3. Effective Speed Factors for F4s

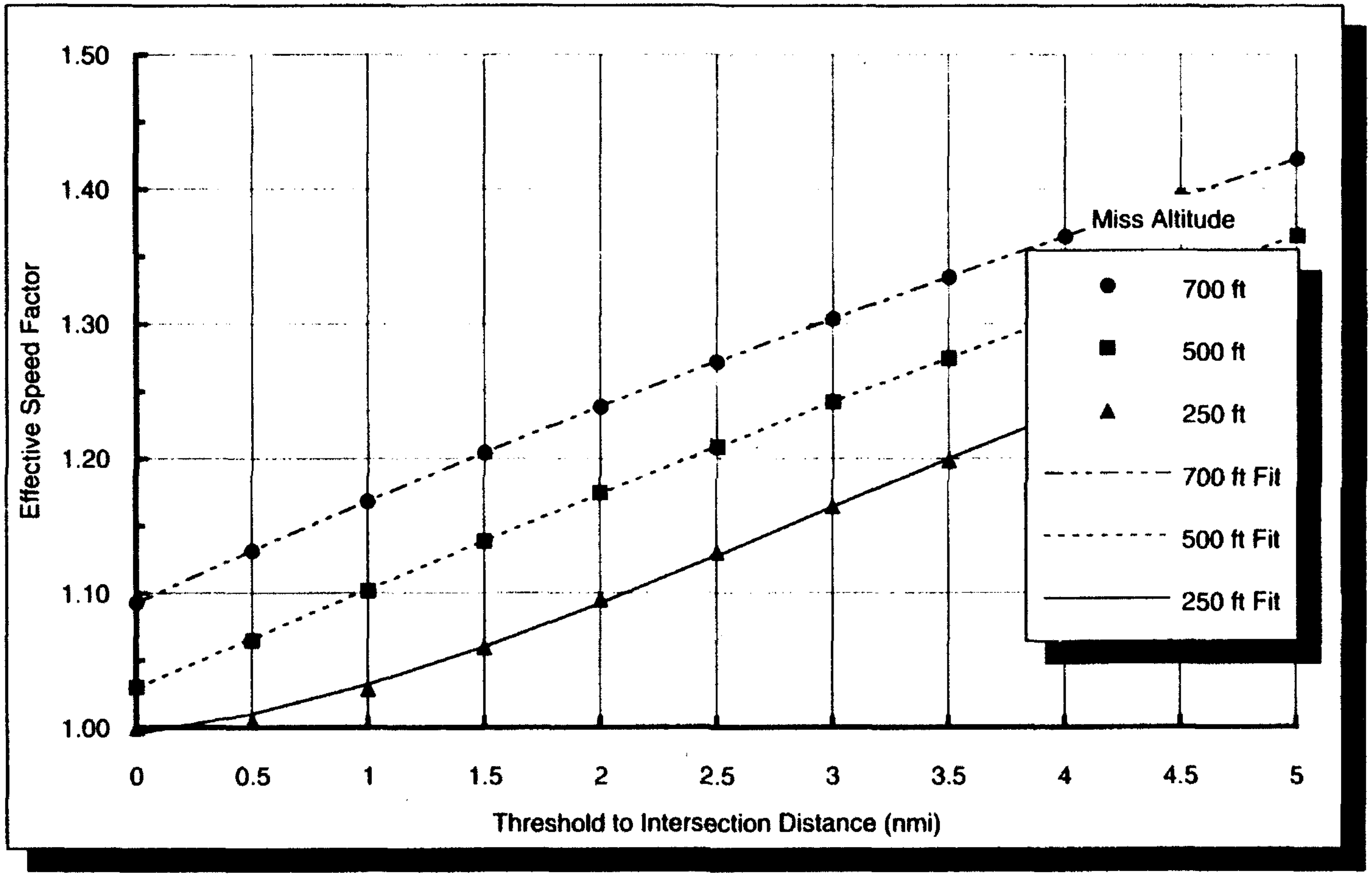

Figure 3-4. Effective Speed Factors for Heavies

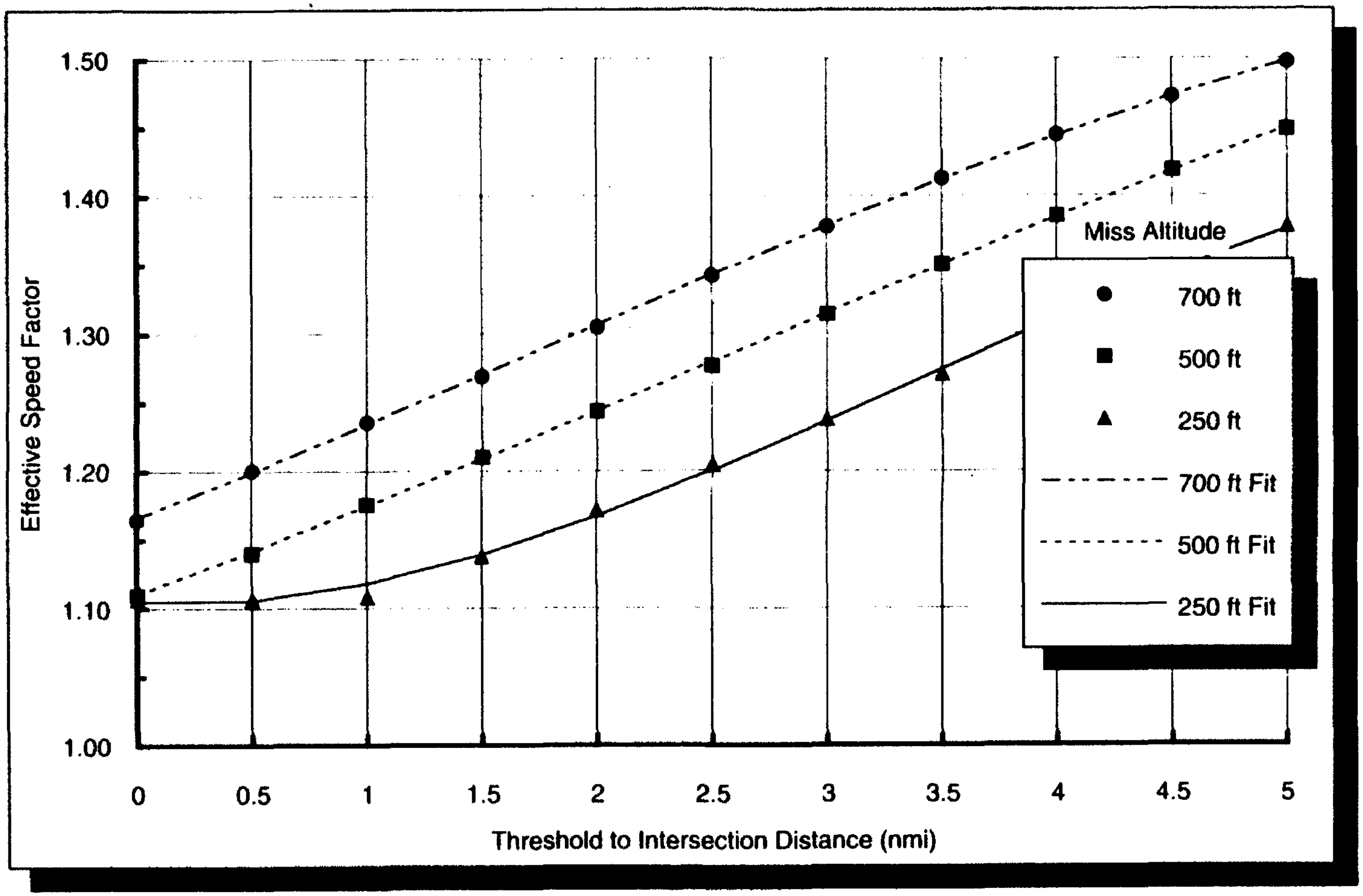

Figure 3-5. Effective Speed Factors for Others

Table 3-2. Maximum Differential and Headwinds

Included Angle Between Runways (Degs)	30	40	50	60	70	80	90	100	110	120
Maximum Differential Wind										
Wind Speed (kts)	15.53	15.81	15.81	15.81	15.81	15.81	15.81	15.81	15.81	15.81
Wind Direction (Degs)*	75.00	68.43	58.43	48.43	38.43	28.43	18.43	8.43	-1.57	-11.57
Difference in Ground Speed (kts)**	8.04	10.81	13.28	15.49	17.39	18.9	20	20.64	20.81	20.49
Maximum Headwind on Leading Aircraft										
Wind Speed (kts)	30.00	30.00	30.00	30.00	26.15	23.34	21.21			
Wind Direction (Degs)*	0.00	-10.00	-20.00	-30.00	-35.00	-40.00	-45.00	Reverts to Max Diff Wind Case		
Difference in Ground Speed (kts)**	4.02	3.56	2.21	0.00	0.00	0.00	0.00			

* Relative to bearing of runway of leading aircraft, positive toward the threshold of the other runway
** Trailing aircraft will always be faster

will be larger given all other conditions are the same. This could be viewed as extra safety, or conversely as an opportunity to relax other conditions to gain an operational advantage at a given airport.

3.4 MODELING OF WORST CASE FACTORS

As the DCIA model was descibed above, several modeling assumptions were made which makes this analysis very conservative. This section summarizes and places into perspective the conservative nature of this model. In addition, the factors that were not explicited modeled are discussed.

3.4.1 Aircraft Accelerations

In general aircraft are expected to perform a constant speed climb and then an acceleration after executing the missed approach (Barker, 1992; Gilligan, 1991b). However, to insure safety even in the most extreme situations the leading aircraft never accelerates; and the trailing aircraft is attributed a constant[5] acceleration value. The acceleration is implemented in the model as an instantaneous change in speed to a higher constant missed approach speed. The missed approach speed is derived separately such that the aircraft arrives at the

5 Climbs are not explicitly modeled in the DCIA analysis.

intersection at the same time as the more detailed modeling of aircraft of its type assuming constanct speed climb to 1500 feet and then a constant acceleration. Appendix B discusses the details of the acceleration modeling.

Another point should be made about the conservative modeling of the trailing aircraft's acceleration. In addition to the accelerations being bounded so as to err towards higher trailer accelerations (which lead to smaller predicted separations), the DCIA model introduces another conservative feature: this kind of acceleration profile gives the trailing aircraft higher speeds in the earlier portion of his miss scenario than would be the case in which an actual constant acceleration were applied. In some scenarios, this feature leads to a slightly more conservative measure of the predicited separation (i.e., smaller separation).

3.4.2 Determination of Headwind Components

The ground speeds of the respective aircraft depend on the headwind (or tailwind) components encountered in the scenario. There are two wind conditions that can lead to a minimum separation depending on the relative speeds involved and the geometry. One condition puts the maximum allowable headwind on the leading aircraft. The other condition yields a wind that generates the maximum differential headwind components on the two aircraft with the greatest headwind on the leading aircraft.

The DCIA model examines both wind conditions for a given scenario and always chooses the wind conditon that results in the minimum predicted separation. Implicit in this analysis is an inclusion of the worst case geometry (included angle between the runways) for a given pair of runway lengths.

3.4.3 Speed Groups

The DCIA model divides the final approach speed spectrum into 10 knot increments ranging from 80 knots to 170 knots. The DCIA procedure is to be carried out with the use of the CRDA. The CRDA ghosts against which the controller sets up the spacing include a speed indicator block which is the computer-derived ground speed of an actual aircraft. Computer-derived speeds are shown rounded to the nearest 10 knots. For example, aircraft with a ground speed of 127 knots would show a '13' in the speed data block on the controller's display to represent 130 kts. For this reason the DCIA model makes a conservative assumption when determining the actual physical speed to use for a given speed class. The actual speed used depends on whether the specified aircraft is leading or trailing. If the aircraft is leading, then the DCIA model chooses the lowest speed in the speed range that would represent that speed class (e.g., a nominal 120 knot leading aircraft will be modeled as having a final approach speed of 115 knots). If the aircraft is the trailing aircraft, then the

DCIA model chooses the highest speed that would represent that speed class (e.g., a nominal 150 knot trailing aircraft will be modeled as having a final approach speed of 154 knots).

Because of the the way speed block rounding is modeled, the DCIA model will show a deleterious speed differential of 9 knots for "equal speed aircraft." This fact plus the fact that there is always an acceleration differential applied (even for the same type aircraft in a scenario) means that it is always possible to find a geometry (albeit extreme) for which a given stagger may be degraded to less than the required separation, even for the scenarios that pair the same aircraft types at the same final approach speed.

3.4.4 Factors Not Modeled in the DCIA Procedure

There are several factors not modeled in the DCIA analytic model. These include: aircraft drift due to wind, variable winds by altitude, climbs, indicated/true air speed correction; and variations on the exact moment of execution of the missed approach (i.e., late/early miss at a given decision height). These factors will be discussed in turn with an explanation of the reasons for not modeling them.

Winds by Altitude. Worst case, constant winds are always used in the DCIA model. Variable winds by altitude are not modeled in the DCIA procedure. This is consistent with the St. Louis simulation which also used a constant wind field. However, the DCIA wind field is more conservative than those specified in the St. Louis simulation[6] in that the worst case wind is applied to every sceanrio. Wind shear is not modeled.

Indicated Airspeed Correction. No explicit correction was made for the conversion from indicated airspeed to true airspeed for three reasons: (1) the effect is small over the altitude range of final approach (typically under 2000 feet AGL), (2) the error, in any case, is in the same direction for both aircraft, and (3) the effect as measured in the St. Louis simulation was on the order of 0.05 nmi which is over an order of magnitude smaller than the separation criteria being measured.

Drift. Drift due to wind is not modeled in the DCIA model. Again that effect in the St. Louis simulation was shown to be on the order of 0.05 nmi in terms of final separation.

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6 Winds in the St. Louis simulation where specified by a Missed Approach Test Plan (Gilligan, 1991b) which, in effect, performed a sampling of worst case factors into a given scenario, never combining all worst case factors into one scenario. In effect the DCIA model combines <u>all</u> worst case factors into <u>every</u> scenario.

Pilot Deviations. Deviations from the published straight-out missed approach procedures are not modeled in the DCIA procedure.

Climbs and Descents. Explicit altitude changes in either the leading or the trailing aircraft are not modeled. In regard to descents, the deceleration zone of the trailing aircraft is consistent with the normal approach along the 3 degree ILS glide slope. As for climbs, the ground speed of the trailing aircraft is determined consistent with the St. Louis simulation which did explicitly model aircraft altitudes. Any altitude separation achieved only adds to the safety of the encounter. However, no altitude separation considerations were used in determining safe operations in this analysis.

3.4.5 Conservative Nature of the DCIA Model.

The DCIA model as described in this section was applied to derive geometry-dependent procedures that provide at least 1 nmi horizontal separation (in the case of a leading non-heavy aircraft) and at least 76 seconds wake vortex avoidance protection. This margin of safety is provided for the following unlikely (and additive) combination of deleterious events: the leading aircraft misses its approach; the stagger is the minimum allowed; there is no radio contact with either aircraft; the trailing aircraft misses its approach; the weather conditions preclude "see and avoid" techniques by either aircraft; the wind conditions are such that the worst allowable wind is operative at the time of the consecutive missed approach event; and that for some reason the leading aircraft cannot or does not accelerate while the trailing aircraft accelerates to the intersection even though dependent staggered approaches are in effect. And finally, the combination of aircraft is such that there is a significant speed differential between the two aircraft, and that the slower aircraft is the leading aircraft. And, as described previously, the aircraft are modeled as flying with final approach speeds at the low end of the speed range (for quantization to nearest 10 kts) for the leader and at the high end of the speed quantization range for the trailer so that their apparent speed differential is maximized. This combination of events is extraordinarily unlikely. Therefore, the safety of this procedure is based on protection against an event that will minimize the separation between the aircraft and that event is very unlikely to happen. Other events that are more likely to happen will result in greater separation between the aircraft.

3.5 VALIDATION OF THE MODEL

This section describes some of the verification and validation excercises that were applied to the St. Louis model on which this analysis is based. The construction of the original St. Louis missed approach model followed the suggestions of Law and Kelton (1982). Among other things, the model itself was developed with a "high face validity", meaning that

the missed approach model conforms to reasonable expectations of knowledgeable individuals (in this case pilots, St. Louis operational personnel, and FAA staff).

The methodoldogy used to develop the St. Louis simulation as an evolving prototype was briefed to the FAA several times, including a final critical design review (CDR). The code was written in structured and modular form, separating logic and data, and was delivered to the FAA for review and scrutiny. The St. Louis simulation was designed in such a way that an audit trail was automatically generated for each scenario that included all of the input parameters and all relevant results on a "scan by scan" basis with one second resolution. The FAA's written report (Richards, 1991) endorsed the methodology and findings of the St. Louis simulation. The St. Louis simulation in its TRACON playback mode was demonstrated to representatives of the FAA. Finally, the simulation was compared to actual consecutive missed approach events that were conducted at St. Louis in July 1991 for the purpose of demonstrating the safety of the DCIA procedure.

The DCIA model which was developed from the St. Louis simulation was also checked for internal consistency over the range of parameters of interest. In addition, the DCIA model was implemented with more detailed acceleration assumptions to check accuracy of the models and calculations. Section 4.2 and appendix E discuss the results of these validation efforts in more detail.

SECTION 4

ANALYSIS

4.1 ANALYSIS PROCEDURES

The model described in section 3 was implemented in a spreadsheet in order to yield the distance and time separation of the aircraft at the intersection. An example of the output of such a spreadsheet is given in table 4-1.

Table 4-1. DCIA Analysis Spreadsheet Example

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		250	Miss Altitude						
		2600	Leader Rwy T-X						
		2600	Trailer Rwy T-X						
		2	Stagger Distance						
		5	Heavy Stagger Distance						
		80							
2600	2600	75	154	1.21		1.21		1.21	
2600	2600	75	164	1.12		1.12		1.12	
2600	2600	75	174	1.01		1.01		1.01	
		90							
2600	2600	85	154	1.43		1.43		1.43	
2600	2600	85	164	1.35		1.35		1.35	
2600	2600	85	174	1.28		1.28		1.28	
		100							
2600	2600	95	154	1.57		1.57		1.57	
2600	2600	95	164	1.51		1.51		1.51	
2600	2600	95	174	1.45		1.45		1.45	
		110							
2600	2600	105	154	1.67		1.67		1.67	
2600	2600	105	164	1.62		1.62		1.62	
2600	2600	105	174	1.57		1.57		1.57	
		120							
2600	2600	115	154	1.74	101	1.74	101	1.74	101
2600	2600	115	164	1.70	95	1.70	95	1.70	95
2600	2600	115	174	1.66	91	1.66	91	1.66	91
		130							
2600	2600	125	154	1.80	103	1.80	103	1.80	103
2600	2600	125	164	1.77	96	1.77	96	1.77	96
2600	2600	125	174	1.73	92	1.73	92	1.73	92

This spreadsheet accounts for all of the factors such as wind, decelerations, and accelerations but only displays the factors that will be varied. The basic parameters are the altitude at which the aircraft will miss, the distances from the runway threshold to intersection of each runway and the stagger distances required for heavy and non-heavy leading aircraft. Each line of the spreadsheet contains the results for the pairing of different speeds of aircraft. For instance, the first row shows an 80 kt aircraft leading[1] (75 kts is the lower end of the 80 kt range) and a 150 kt aircraft trailing[2] (154 kts is the upper end of the 150 kt range). The separation at the intersection[3] is 1.21 nmi. If the runways were switched and the 80 kt aircraft were leading on the other runway, then the separation (Switch SepMin) would still be 1.21 nmi because the distances from the threshold to the intersection in this case is 2600 feet for both runways. The column labeled "MinSep" is the minimum of the two SepMin columns. The TMin columns are the time separations for the heavy leading situations. The slowest heavy aircraft is modeled with a final approach airspeed of 120 kts so the other entries slower than this are left blank.

Since the minimum distance and time separations result from combinations of slow leading aircraft with fast trailing aircraft, only the slowest and fastest speed groups need to be considered. Because aircraft up to 120 kts can be restricted to the runway with the shorter threshold to intersection distance only leading aircraft with speeds up to 130 kts need to be considered. The slowest heavy leading aircraft are covered by this speed group range. For the fastest trailing aircraft one needs to consider the 150 kt through 170 kt speed groups. The 150 kt speed group is included here because the 160 kt and greater aircraft can be "excepted" from the procedure.

The analysis methodology was designed to find those ranges of runway threshold-to-intersection distances for which a common set of restrictions would apply. For instance, from table 4-1 one can see that when the threshold-to-intersection lengths for both runways were 2600 feet, the separation at the intersection following a consecutive missed approach between the 80 kt leading aircraft and the 170 kt trailing aircraft would be 1.01 nmi. (It is not exactly 1.00 nmi because the threshold to intersection distances have to be integral numbers of 100 feet.) When an 80 kt leading aircraft and a 170 kt trailing aircraft yields at least a 1.00 nmi separation, and a 76 second minimum time separation (it is 91 seconds in

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1 FASL is "Final Approach Speed of the Leader"

2 FAST is "Final Approach Speed of the Trailer"

3 SepMin is the minimum separation after taking into account the worst case wind conditions.

the example in table 4-1), the operation is unrestricted. In other words any aircraft can be paired with any other aircraft on either runway.

This establishes 2600 feet as a "breakpoint" for the shorter and longer threshold-to-intersection distances. In other words, any configurations with threshold-to-intersection distances less than 2600 feet could safely support an unrestricted DCIA procedure with 2 nmi stagger behind a non-heavy aircraft and 5 nmi stagger behind a heavy aircraft. Being safe means that the minimum separation at the intersection would be greater than 1.00 nmi behind a non-heavy aircraft and 76 seconds of time separation behind a heavy aircraft. If either runway's threshold-to-intersection distance were greater than 2600 feet, then an unrestricted DCIA procedure with a (2,5) stagger[4] could result in an intersection separation of less than 1.00 nmi behind a non-heavy aircraft or a time separation of less than 76 seconds behind a heavy aircraft.

The analysis then proceeds to find the conditions under which a runway configuration can be operated safely with the shorter threshold-to-intersection distance being 2600 feet and the longer threshold to intersection distance being greater than 2600. Consider the spreadsheet in table 4-2. This table shows that a longer threshold-to-intersection distance of 3200 feet results in an intersection separation of 1.02 nmi between an 80 kt leading aircraft and a 150 kt trailing aircraft. However, because a 1.00 nmi separation cannot be assured over the entire range of approach speeds (i.e., between an 80 kt and a 170 kt aircraft) then there needs to be a restriction. One could express such a restriction for this case in two ways. One could either say not to pair 80 kt or less leading aircraft with 160 kt or greater trailing aircraft or just not let 160 kt or greater aircraft be staggered 2 nmi behind any other aircraft. This last restriction is obviously more restrictive than the former[5]. The criteria for the leading heavy is also covered in this situation with 89 seconds if the "do not pair 80 kt with 160 kt aircraft" restriction is observed or 100 seconds if the "except 160 kt aircraft" restriction is observed.

The next breakpoint is found at 4500 feet for the longer threshold to intersection distance (see table 4-3). There are several ways in which this table can be interpreted. Notice that in several places the separation is less than 1.00 nmi, sometimes as little as 0.15 nmi. Recall that the left-most "SepMin" column gives the separation when the leading and trailing

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4 The nomenclature (x,y) when associated with a stagger means that the minimum required stagger behind a non-heavy aircraft is x nmi while the minimum required stagger behind a heavy aircraft is y nmi.

5 In this analysis the 160 kt and 170 kt speed groups are always grouped together because the entire range represents a limited number of aircraft types and to further differentiate these groups would not make a difference operationally.

Table 4-2. Second Breakpoint Spreadsheet

250 Miss Altitude
2600 Leader Rwy T-X
3200 Trailer Rwy T-X
2 Stagger Distance
5 Heavy Stagger Distance

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		80							
2600	3200	75	154	1.21		1.02		1.02	
2600	3200	75	164	1.11		0.88		0.88	
2600	3200	75	174	0.99		0.74		0.74	
		90							
2600	3200	85	154	1.43		1.30		1.30	
2600	3200	85	164	1.35		1.20		1.20	
2600	3200	85	174	1.28		1.11		1.11	
		100							
2600	3200	95	154	1.57		1.47		1.47	
2600	3200	95	164	1.51		1.40		1.40	
2600	3200	95	174	1.45		1.33		1.33	
		110							
2600	3200	105	154	1.67		1.59		1.59	
2600	3200	105	164	1.62		1.53		1.53	
2600	3200	105	174	1.57		1.47		1.47	
		120							
2600	3200	115	154	1.74	101	1.68	100	1.68	100
2600	3200	115	164	1.70	95	1.63	93	1.63	93
2600	3200	115	174	1.66	90	1.58	89	1.58	89
		130							
2600	3200	125	154	1.80	103	1.76	101	1.76	101
2600	3200	125	164	1.77	96	1.71	95	1.71	95
2600	3200	125	174	1.73	92	1.66	91	1.66	91

threshold-to-intersection distances are as shown in that row (i.e., the shorter distance associated with the leading aircraft). The "Switch SepMin" column reverses the runways that the leading and trailing aircraft use. Therefore, in order to avoid separations of less than 1.00 nmi one could restrict the slower aircraft to the runway with the shorter threshold-to-intersection distance. Notice in table 4-3 that if this condition were applied to aircraft with approach speeds of 90 kts or less most of the separations would be greater than 1.00 nmi. However, when an 80 kt aircraft is leading, the separation resulting from a 170 kt trailing aircraft could be only 0.93 nmi. If a restriciton of not pairing a leading 80 kt or less aircraft

Table 4-3. Third Breakpoint Spreadsheet

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		250	Miss Altitude						
		2600	Leader Rwy T-X						
		4500	Trailer Rwy T-X						
		2	Stagger Distance						
		5	Heavy Stagger Distance						
		80							
2600	4500	75	154	1.19		0.58		0.58	
2600	4500	75	164	1.05		0.35		0.35	
2600	4500	75	174	0.93		0.15		0.15	
		90							
2600	4500	85	154	1.43		1.01		1.01	
2600	4500	85	164	1.35		0.85		0.85	
2600	4500	85	174	1.25		0.69		0.69	
		100							
2600	4500	95	154	1.57		1.25		1.25	
2600	4500	95	164	1.51		1.16		1.16	
2600	4500	95	174	1.45		1.05		1.05	
		110							
2600	4500	105	154	1.67		1.42		1.42	
2600	4500	105	164	1.62		1.34		1.34	
2600	4500	105	174	1.57		1.25		1.25	
		120							
2600	4500	115	154	1.74	101	1.55	96	1.55	96
2600	4500	115	164	1.70	94	1.48	90	1.48	90
2600	4500	115	174	1.66	89	1.40	86	1.40	86
		130							
2600	4500	125	154	1.80	103	1.66	99	1.66	99
2600	4500	125	164	1.77	95	1.59	92	1.59	92
2600	4500	125	174	1.73	90	1.53	88	1.53	88

with a 160 kt[6] or greater aircraft were imposed, then the separation of 0.93 nmi would be eliminated. Therefore if both the restriction to the shorter threshold-to-intersection runway and the "no pairing" restriction held, then for all other combinations of speed groups the required 1.00 nmi intersection separation would be satisfied.

6 The aircraft with approach speeds of 160 kts and 170 kts are grouped together for the purposes of this analysis for the reasons explained in the previous footnote.

This is not the only set of restrictions that could apply here, however. Notice that if the 160 kt or greater aircraft were "excepted" and the 80 kt or less aircraft were restricted to the runway with the shorter threshold-to-intersection distance the same effect could be achieved. Furthermore, not pairing the 90 kt or less aircraft leading with the 160 kt or greater aircraft and restricting the 80 kt or less aircraft to the runway with the shorter threshold to intersection distance could also achieve the same effect. Depending on the traffic mix at the airport in question, one or another of these restrictions may be more appropriate. In table 4-3 the time separation behind a heavy is not an issue with a minimum time separation of 86 seconds.

The process of finding the next longer threshold-to-intersection distance which gives an intersection separation of equal to or greater than 1.00 nmi and 76 seconds for various approach speed combinations is continued until no restrictions of the types listed in table 3-1 can be applied. When this limit is reached, the next shorter threshold-to-intersection breakpoint is found. This is the threshold-to-intersection distance where the 90 kt and more aircraft are unrestricted. This happens at 3400 feet as shown in table 4-4. In this case the 80 kt or less aircraft have to be excepted. This entire process is continued until absolutely all of the restriction possibilities are exhausted.

All of the foregoing analysis was done assuming that the stagger distances were 2 nmi and 5 nmi for non-heavy and heavy leading aircraft, respectively. According to the conditions agreed to in table 3-1, the stagger distances for non-heavy leaders could also be 2.5 nmi and 3 nmi and the stagger distance for heavy leaders could also be 6 nmi. With the "breakpoints" defined for 2 nmi and 5 nmi stagger, the spreadsheets were run again for the other combinations of stagger distances. Each of these spreadsheets with other stagger distances were interpreted to derive the restrictions which would insure the proper intersection separations. As will be seen in the results in section 5, increasing the stagger distances reduces the severity of the restrictions. Of course, the tradeoff is that the capacity will be lowered.

This entire procedure was then repeated for the miss altitudes of 500 and 700 feet.

The final element of the analysis was to determine the appropriate stagger distances for the aircraft that were "excepted." The basic rule for considering "excepted" aircraft is that if there is a runway restriction (e.g., restrict 80 kt or less aircraft to the runway with the shorter threshold to intersection distance) for a given runway configuration, then that restriction still applies when the "excepted" aircraft is allowed to be part of the procedure. Consider table 4-5 as an example of how such a case is analyzed. In this example there is a 110 kt restriction (meaning that aircraft which are 110 kts or less must be assigned to the runway with the shorter threshold-to-intersection distance). This means that a 120 kt aircraft must be separated from a 170 kt aircraft by 1.00 nmi for all situations (i.e., runway assignment and

Table 4-4. Next Shorter Threshold to Intersection Breakpoint Spreadsheet

250 Miss Altitude
3400 Leader Rwy T-X
3400 Trailer Rwy T-X
2 Stagger Distance
5 Heavy Stagger Distance

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		80							
3400	3400	75	154	0.94		0.94		0.94	
3400	3400	75	164	0.77		0.77		0.77	
3400	3400	75	174	0.61		0.61		0.61	
		90							
3400	3400	85	154	1.26		1.26		1.26	
3400	3400	85	164	1.15		1.15		1.15	
3400	3400	85	174	1.02		1.02		1.02	
		100							
3400	3400	95	154	1.44		1.44		1.44	
3400	3400	95	164	1.37		1.37		1.37	
3400	3400	95	174	1.29		1.29		1.29	
		110							
3400	3400	105	154	1.56		1.56		1.56	
3400	3400	105	164	1.50		1.50		1.50	
3400	3400	105	174	1.44		1.44		1.44	
		120							
3400	3400	115	154	1.66	99	1.66	99	1.66	99
3400	3400	115	164	1.61	92	1.61	92	1.61	92
3400	3400	115	174	1.55	88	1.55	88	1.55	88
		130							
3400	3400	125	154	1.74	101	1.74	101	1.74	101
3400	3400	125	164	1.69	94	1.69	94	1.69	94
3400	3400	125	174	1.64	90	1.64	90	1.64	90

leading/trailing status) and all 110 kt or less aircraft must be separated from all other aircraft by more than 1.00 nmi when the 110 kt or less aircraft are assigned to the runway with the shorter threshold-to-intersection distance. In table 4-5 the non-heavy stagger distance was determined such that the 120 kt leading/170 kt trailing case is separated by exactly 1.00 nmi. At the same time the heavy stagger distance was determined such that the 120 kt leading heavy/170 kt trailing case is separated by exactly 76 sec. The 3.3872 nmi non-heavy stagger distance was then rounded up to 3.5 nmi and the 6.3228 nmi heavy stagger distance was rounded up to 7 nmi in keeping with the half-mile stagger increments for non-heavy leading aircraft and the one mile stagger increments for heavy leading aircraft found in table 3-1.

Table 4-5. Excepted Aircraft Analysis With Restriction

250 Miss Altitude
3400 Leader Rwy T-X
17800 Trailer Rwy T-X
3.3872 Stagger Distance
6.3228 Heavy Stagger Distance

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		80							
3400	17800	75	154	2.02		-2.79		-2.79	
3400	17800	75	164	1.61		-3.73		-3.73	
3400	17800	75	174	1.43		-4.32		-4.32	
		90							
3400	17800	85	154	2.39		-1.08		-1.08	
3400	17800	85	164	2.07		-1.73		-1.73	
3400	17800	85	174	1.92		-2.18		-2.18	
		100							
3400	17800	95	154	2.65		0.07		0.07	
3400	17800	95	164	2.38		-0.34		-0.34	
3400	17800	95	174	2.26		-0.70		-0.70	
		110							
3400	17800	105	154	2.81		0.79		0.79	
3400	17800	105	164	2.62		0.54		0.54	
3400	17800	105	174	2.51		0.30		0.30	
		120							
3400	17800	115	154	2.94	119	1.36	87	1.36	87
3400	17800	115	164	2.78	104	1.20	81	1.20	81
3400	17800	115	174	2.70	98	1.00	76	1.00	76
		130							
3400	17800	125	154	3.04	121	1.79	97	1.79	97
3400	17800	125	164	2.90	106	1.65	90	1.65	90
3400	17800	125	174	2.83	100	1.51	86	1.51	86

If the runway configuration does not require a restriction, then including an "excepted" aircraft into the operation means that an 80 kt leading aircraft and a 170 kt trailing aircraft must be accommodated. An example of the analysis for this situation is shown in table 4-6. The non-heavy separation at the intersection between an 80 kt leading aircraft and a 170 kt trailing aircraft is 1.00 nmi. The stagger to achieve this is 2.2151 nmi. At the same time the required heavy stagger to achieve 76 seconds between a 120 kt leading heavy and a 170 kt trailing aircraft is 4.3542 nmi.

Table 4-6. Excepted Aircraft Analysis With Restriction

250 Miss Altitude
2600 Leader Rwy T-X
3200 Trailer Rwy T-X
2.2151 Stagger Distance
4.3542 Heavy Stagger Distance

Lead T-X	Trail T-X	FASL	FAST	SepMin	TMin	Switch SepMin	TMin	Min Sep	Min Time
		80							
2600	3200	75	154	1.43		1.24		1.24	
2600	3200	75	164	1.33		1.13		1.13	
2600	3200	75	174	1.24		1.00		1.00	
		90							
2600	3200	85	154	1.65		1.51		1.51	
2600	3200	85	164	1.57		1.42		1.42	
2600	3200	85	174	1.49		1.32		1.32	
		100							
2600	3200	95	154	1.78		1.68		1.68	
2600	3200	95	164	1.73		1.62		1.62	
2600	3200	95	174	1.67		1.54		1.54	
		110							
2600	3200	105	154	1.88		1.80		1.80	
2600	3200	105	164	1.83		1.74		1.74	
2600	3200	105	174	1.78		1.68		1.68	
		120							
2600	3200	115	154	1.96	88	1.90	86	1.90	86
2600	3200	115	164	1.91	82	1.84	80	1.84	80
2600	3200	115	174	1.87	77	1.79	76	1.79	76
		130							
2600	3200	125	154	2.02	89	1.97	88	1.97	88
2600	3200	125	164	1.98	83	1.93	82	1.93	82
2600	3200	125	174	1.94	79	1.88	78	1.88	78

4.2 SECOND ORDER MODEL

A second order model was developed independently of the model described in section 3 and was used for three verification and validation functions:

a. Verification of the model equations and software
b. Evaluation of the stability of model's numerical calculations
c. Corroboration of DCIA procedure restrictions

Conceptually, the second order model and the original DCIA model described in section 3 are the same except the second order model models the trailer missed approach maneuver (from the missed approach point to the intersection of the runway centerlines) using a constant acceleration rather than an instantaneous increase in speed. The constant acceleration is chosen so that if there were no wind the trailing aircraft would reach the intersection of the runway centerlines at the same time as it would have using the original model. Because wind is constant in both models, it follows that the trailer reaches the intersection of the runway centerlines at the same time in both models even when wind is taken into account.

Because both models are identical except for the missed approach maneuver of the trailing aircraft, the separation computed by both models is the same if the trailing aircraft has not yet reached its missed approach point when the leader reaches the intersection of the runway centerlines. In the original model, the trailing aircraft takes a time, say T, to travel from its missed approach point to the intersection of the runway centerlines. The second order model's acceleration causes the trailing aircraft to attain the missed approach speed used in the original model at time T/2. Therefore, until time T/2 the second order model's trailing aircraft is traveling slower than the orginal model's trailing aircraft. Since the trailing aircraft reaches the intersection of the runway centerlines at the same time in both models, it follows that during the missed approach maneuver, the second order model's trailing aircraft is always behind the the original model's trailing aircraft. This implies that the separation computed by the second order model is always at least as large as that computed by the original model described above. Therefore, the second order model is slightly less conservative than the original model. Moreover, because the two models are so similar and the acceleration is a second order effect, the separations they compute are comparable.

The orginal model was implemented as a spreadsheet model on an IBM PC compatible computer while the second order model was developed and implemented independently using the Mathematica programming language on a Macintosh computer[7]. Hence, direct comparison of equations and model outputs were sufficient to verify the original model's equations and software. The results of this comparison can be found in section 5.3.

7 IBM is a registered tradmark of the International Business Machines Corporation, Macintosh is a registered trademark of Apple Computer, Incorporated, and Mathematica is a registered trademark of Wolfram Research, Inc.

SECTION 5

RESULTS

5.1 GENERAL DCIA PROCEDURE

The analysis that was described in section 4 was performed and the results are shown in tables 5-1, 5-2 and 5-3. These tables are appropriate for decision heights of 250 feet or less, decision heights between 251 feet and 500 feet, and decision heights between 501 feet and 700 feet, respectively. These tables have been set up to allow a facility with a given runway configuration to determine which stagger distances and which restrictions apply to their operations. The following discussion lists the steps necessary to be taken by a facility to use the table.

1. Identify all the runway configurations for which the facility wishes to use the DCIA procedure. For each runway configuration, follow steps 2 through 6 below.

2. Determine the point of intersection of the two converging runways or their extended centerlines. Determine the distances from each runway threshold to the intersection point.

3. Determine the decision heights for each runway and select the larger of the two decision heights.

4. If the decision height determined in step 3 is 250 ft or less, use table 5-1. If the decision height determined in step 3 is between 251 ft and 500 ft, use table 5-2. If the decision height determined in step 3 is between 501 ft and 700 ft, use table 5-3.

5. Within the table chosen in Step 4, go to the row that covers the runway configuration (i.e., the combination of threshold-to-intersection distances determined in step 2) to find the DCIA procedure that the facility may use for this configuration. The procedure is determined by the stagger value required and certain restrictions and/or exceptions. All of the options provide the required level of safety. The tradeoff is between the potential throughput and the severity of the restrictions. If several options are identified, the facility may select one that is most operationally suitable. It is expected that the facility will express the restrictions and exceptions in terms of aircraft types (e.g., 80 kt or less aircraft could be classified as single engine general aviation aircraft) that are meaningful

Table 5-1. DCIA Procedure for Decision Heights of 250 ft or Less

	Shorter distance from threshold to intersection	Longer distance from threshold to intersection	**DCIA Procedure** Stagger aircraft to converging runways using indicated stagger distances; restrictions noted	Stagger rule for "Excepted" aircraft
1	Up to 2600 ft	Up to 2600 ft	● No restrictions; **stagger rule is (2,5)**	NA
2	Up to 2600 ft	2601 ft to 3200 ft	● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)**	NA
			or	
			● Except 160 kt or greater aircraft; **stagger rule is (2,5)**	(2.5,5) or skip a slot
			or	
			● No restrictions; **stagger rule is (2.5,5)**	NA
3	Up to 2600 ft	3201 ft to 4500 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)**	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2,5)**	(2.5,5) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)**	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,5)**	NA
			or	
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	NA
			or	

			● No restrictions; **stagger rule is (3,5)**	NA
4	Up to 2600 ft	4501 ft to 5900 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)** **or**	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(2.5,5) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)** **or**	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,5)** **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or**	NA
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)** **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,5)**	NA

5	Up to 2600 ft	5901 ft to 7500 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or	NA
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or	(2.5,5) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or	NA
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5)	NA
6	Up to 2600 ft	7501 ft to 9700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or	(2.5,6) or skip a slot

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or**	(2.5,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or**	(3,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2,6)** **or**	(2.5,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,6)** **or**	NA
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	NA
7	Up to 2600 ft	9701 ft to 10600 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(2.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or**	(2.5,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or**	(3.5,6) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	NA NA
8	Up to 2600 ft	10601 ft to 12200 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	(3,6) or skip a slot NA (3.5,6) or skip a slot NA NA
9	Up to 2600 ft	12201 ft to 13900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	(3,6) or skip a slot NA

10	Up to 2600 ft	13901 ft to 17600 ft	• Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)**	(3,7) or skip a slot
11	Up to 2600 ft	17601 ft to 19700 ft	• Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3,7) or skip a slot
12	2601 ft to 3400 ft	Up to 3400 ft	• Except 80 kt or less aircraft; **stagger rule is (2,5)** **or** • No restrictions; **stagger rule is (2.5,5)**	(2.5,5) or skip a slot NA
13	2601 ft to 3400 ft	3401 ft to 4000 ft	• Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft; **stagger rule is (2,5)** **or** • Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2,5)** **or** • Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,5)** **or** • Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or** • No restrictions; **stagger rule is (3,5)**	(2.5,5) or skip a slot (3,5) or skip a slot NA NA NA
14	2601 ft to 3400 ft	4001 ft to 5800 ft	• Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2,5)** **or**	(2.5,5) or skip a slot

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) **or**	(2.5,5) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2.5,5) **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,5) **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,5) **or**	NA
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (3,5)	NA
15	2601 ft to 3400 ft	5801 ft to 7500 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) **or**	(2.5,5) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2.5,5) **or**	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,5) **or**	NA

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (3,5)	NA NA
16	2601 ft to 3400 ft	7501 ft to 9700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) or ● Restrict 110 kt or lesss aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,6)	(3,6) or skip a slot (3,6) or skip a slot (3,6) or skip a slot NA NA
17	2601 ft to 3400 ft	9701 ft to 12100 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) or	(3,6) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	(3,6) or skip a slot (3,6) or skip a slot NA NA
18	2601 ft to 3400 ft	12101 ft to 13900 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	NA NA
19	2601 ft to 3400 ft	13901 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,7) or skip a slot
20	3401 ft to 4400 ft	Up to 4400 ft	● Except 80 kt or less aircraft **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)** **or**	(3,5) or skip a slot

			● Except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or	(3,5) or skip a slot
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	NA
			● No restrictions; stagger rule is (3,5)	NA
21	3401 ft to 4400 ft	4401 ft to 5800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2,5) or	(3,5) or skip a slot
			● Except 90 kt or less aircraft and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or	(3.5,5) or skip a slot
			● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or	(3.5,5) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5) or	NA

			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
22	3401 ft to 4400 ft	5801 ft to 7400 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(3,5) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or**	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or**	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,5)** **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
23	3401 ft to 4400 ft	7401 ft to 9600 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(3,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or**	(3,6) or skip a slot

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or**	(3.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)** **or**	(3,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
24	3401 ft to 4400 ft	9601 ft to 12200 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(3.5,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or**	(3.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or**	(3.5,6) or skip a slot
			● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)** **or**	(3.5,6) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
25	3401 ft to 4400 ft	12201 ft to 13900 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3.5,6) or skip a slot NA NA
26	3401 ft to 4400 ft	13901 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,7) or skip a slot
27	4401 ft to 5700 ft	Up to 5700 ft	● Except 90 kt or less aircraft **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)** **or** ● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Except 80 kt or less aircraft **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or**	(3.5,5) or skip a slot (3.5,5) or skip a slot (3.5,5) or skip a slot

			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
28	4401 ft to 5700 ft	5701 ft to 6500 ft	● Except 80 kt or less aircraft **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	(4,5) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
29	4401 ft to 5700 ft	6501 ft to 7200 ft	● Except 80 kt or less aircraft **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	(4,5) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
30	4401 ft to 5700 ft	7201 ft to 12100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)**	(4,6) or skip a slot
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)**	(4,6) or skip a slot
			or	
			● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)**	(4,6) or skip a slot
			or	

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft with 160 kt or greater aircraft; **stagger rule is (3,6)**	NA
31	4401 ft to 5700 ft	12101 ft to 13800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4,6) or skip a slot (4,6) or skip a slot
32	4401 ft to 5700 ft	13801 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot
33	5701 ft to 6400 ft	Up to 6400 ft	● Except 80 kt or less aircraft **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or** ● Except 80 kt or less aircraft; **stagger rule is (3,5)**	(4,5) or skip a slot (4,5) or skip a slot
34	5701 ft to 6400 ft	6401 ft to 6900 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft; **stagger rule is (3,5)** **or**	(4,5) or skip a slot (4,5) or skip a slot

			● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is** (3,5)	NA
35	5701 ft to 6400 ft	6901 ft to 10800 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is** (3,6)	(4,6) or skip a slot (4,6) or skip a slot (4,6) or skip a slot
36	5701 ft to 6400 ft	10801 ft to 12100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or** ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is** (2.5,6) **or**	(4,6) or skip a slot (4,6) or skip a slot (4,6) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4,6) or skip a slot
37	5701 ft to 6400 ft	12101 ft to 13800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4,6) or skip a slot (4,6) or skip a slot
38	5701 ft to 6400 ft	13801 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4.5,7) or skip a slot
39	6401 ft to 8300 ft	Up to 8300 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (2.5,6)** **or** ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4.5,6) or skip a slot (4.5,6) or skip a slot (4.5,6) or skip a slot (4.5,6) or skip a slot

40	6401 ft to 8300 ft	8301 ft to 8700 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or**	(4.5,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or**	(4.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is** (2.5,6) **or**	(4.5,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is** (3,6)	(4.5,6) or skip a slot
41	6401 ft to 8300 ft	8701 ft to 11100 ft	● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is** (3,6)	(5.5,6) or skip a slot
42	6401 ft to 8300 ft	11101 ft to 14000 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,6)	(5,7) or skip a slot
43	6401 ft to 8300 ft	14001 ft to 17700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,6)	(5,7) or skip a slot
44	8301 ft to 10800 ft	Up to 10800 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or**	(5.5,6) or skip a slot

			● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (3,6)	(5.5,6) or skip a slot

Table 5-2. DCIA Procedure for Decision Heights Between 251 ft and 500 ft

	Shorter distance from threshold to intersection	Longer distance from threshold to intersection	**DCIA Procedure** Stagger aircraft to converging runways using indicated stagger distance; restrictions noted	Stagger rule for "Excepted" aircraft
1	Up to 2100 ft	Up to 2100 ft	● No restrictions; **stagger rule is** (2,5)	NA
2	Up to 2100 ft	2101 ft to 2800 ft	● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5)	NA
			or ● Except 80 kt or less aircraft; **stagger rule is** (2,5)	(2.5,5) or miss a slot
			or ● Except 160 kt or greater aircraft; **stagger rule is** (2,5)	(2.5,5) or miss a slot
			or ● No restrictions; **stagger rule is** (2.5,5)	NA
3	Up to 2100 ft	2801 ft to 3700 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5)	NA
			or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2,5)	(2.5,5) or skip a slot
			or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft; **stagger rule is** (2,5)	(2.5,5) or skip a slot
			or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2.5,5)	NA
			or ● No restrictions; **stagger rule is** (3,5)	NA

4	Up to 2100 ft	3701 ft to 4900 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5) **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft; **stagger rule is** (2,5) **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2.5,5) **or** ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (3,5) **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,5)	NA (2.5,5) or skip a slot (2.5,5) or skip a slot NA NA NA
5	Up to 2100 ft	4901 ft to 5900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5) **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft; **stagger rule is** (2,5) **or**	NA (2.5,5) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule** is (2,5) **or**	(2.5,5) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule** is (2.5,5) **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule** is (2.5,5) **or**	(3,5) or skip a slot
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule** is (3,5) **or**	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule** is (3,5)	NA
6	Up to 2100 ft	5901 ft to 7000 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule** is (2,5) **or**	(2.5,5) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule** is (2.5,5) **or**	(3,5) or skip a slot
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 120 kt or less aircraft with 160 kt or greater aircraft; **stagger rule** is (3,5) **or**	NA

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)**	(3.5,5) or skip a slot
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,6)**	NA
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)**	NA
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)**	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
7	Up to 2100 ft	7001 ft to 8900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2,5)**	(2.5,6) or skip a slot
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)**	(3,6) or skip a slot
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)**	(3.5, 6) or skip a slot
			or	

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2.5,6) or	NA
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,6) or	NA
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,6) or	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (3,6)	NA
8	Up to 2100 ft	8901 ft to 11200 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) or	(2.5,5) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) or	(3,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) or	(3.5,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (3,6) or	NA

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
9	Up to 2100 ft	11201 ft to 13100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3,6) or skip a slot NA NA
10	Up to 2100 ft	13101 ft to 17000 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,7) or skip a slot
11	2101 ft to 3800 ft	Up to 3800 ft	● Except 80 kt or less **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Except 80 kt or less aircraft **and** do not pair 100 kt or less aircraft with 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Do not pair 80 kt or less aircraft with 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● No restrictions; stagger rule is (3,5)	(3,5) or skip a slot (3,5) or skip a slot NA NA

12	2101 ft to 3800 ft	3801 ft to 4100 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)** **or** ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or** ● No restrictions; **stagger rule is (3,5)**	(3,5) or skip a slot NA NA NA
13	2101 ft to 3800 ft	4101 ft to 6700 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,6)** **or**	(3,6) or skip a slot (3,6) or skip a slot (3.5,6) or skip a slot NA

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6) or	NA
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
14	2101 ft to 3800 ft	6701 ft to 8600 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or	(3,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	(3,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or	(3.5,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (2.5,6) or	(3,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6) or	NA

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft with 160 kt or greater aircraft; **stagger rule is (3,6)**	NA
15	2101 ft to 3800 ft	8601 ft to 11000 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft with 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,6) or skip a slot (3.5,6) or skip a slot (3.5,6) or skip a slot NA NA
16	2101 ft to 3800 ft	11001 ft to 12900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or**	(3.5,6) or skip a slot

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
17	2101 ft to 3800 ft	12901 ft to 16900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,7) or skip a slot
18	3801 ft to 5000 ft	Up to 5000 ft	● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (2,5)** **or** ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,5)** **or** ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	(3.5,5) or skip a slot (3.5,5) or skip a slot NA
19	3801 ft to 5000 ft	5001 ft to 5900 ft	● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(4,6) or skip a slot (3.5,6) or skip a slot (4,6) or skip a slot NA

20	3801 ft to 5000 ft	5901 ft to 7900 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3.5,6) or skip a slot (4,6) or skip a slot (3.5,6) or skip a slot NA
21	3801 ft to 5000 ft	7901 ft to 9600 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(4,6) or skip a slot (4,6) or skip a slot NA

22	3801 ft to 5000 ft	9601 ft to 10800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(4,6) or skip a slot (4,6) or skip a slot NA
23	3801 ft to 5000 ft	10801 ft to 12700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot (4,7) or skip a slot
24	3801 ft to 5000 ft	12701 ft to 16700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot
25	5001 ft to 7400 ft	Up to 7400 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or**	(4.5,6) or skip a slot (4.5,6) or skip a slot

			● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (2.5,6)** **or** ● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4.5,6) or skip a slot (4.5,5) or skip a slot
26	5001 ft to 7400 ft	7401 ft to 10200 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft with 160 kt or greater aircraft **and** except 90 kt or less aircraft; **stagger rule is (3,6)**	(5.5,6) or skip a slot (5.5,6) or skip a slot
27	5001 ft to 7400 ft	10201 ft to 13000 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(5,7) or skip a slot
28	5001 ft to 7400 ft	13001 ft to 16300 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(5,7) or skip a slot
29	7401 ft to 9700 ft	Up to 9700 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (3,6)**	(5.5,6) or skip a slot (5.5,6) or skip a slot

Table 5-3. DCIA Procedure for Decision Heights Between 501 ft and 700 ft

	Shorter distance from threshold to intersection	Longer distance from threshold to intersection	**DCIA Procedure** Stagger aircraft to converging runways using indicated stagger distance; restrictions noted	Stagger rule for "Excepted" aircraft
1	Up to 1600 ft	Up to 1600 ft	● No restrictions; **stagger rule is** (2,5)	NA
2	Up to 1600 ft	1601 ft to 2100 ft	● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5)	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2,5)	NA
			or	
			● No restrictions; **stagger rule is** (2.5,5)	NA
3	Up to 1600 ft	2101 ft to 2800 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2,5)	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5)	NA
			or	
			● No restrictions; **stagger rule is** (2.5,5)	NA
4	Up to 1600 ft	2801 ft to 3700 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is** (2,5)	NA
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2,5)	NA
			or	

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,5)**	NA
			or	
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	NA
			or	
			● No restrictions; **stagger rule is (3,5)**	NA
5	Up to 1600 ft	3701 ft to 4800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)**	NA
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2,5)**	NA
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (2.5,5)**	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)**	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; **stagger rule is (3,5)**	NA
			or	
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,5)**	NA
			or	

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft with 160 kt or greater; stagger rule is (2,6)	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6)	NA
			or	
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
6	Up to 1600 ft	4801 ft to 6100 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5)	(2.5,6) or skip a slot
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5)	(3,6) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5)	(3.5,6) or skip a slot
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6)	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA

7	Up to 1600 ft	6101 ft to 7900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or	(2.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	(3,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or	(3.5,6) or skip a slot
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6) or	NA
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
8	Up to 1600 ft	7901 ft to 9900 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or	(2.5,6) or skip a slot
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	(3,6) or skip a slot

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3.5,6) or skip a slot NA
9	Up to 1600 ft	9901 ft to 12100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3,6) or skip a slot NA
10	Up to 1600 ft	12101 ft to 16000 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(3.5,7) or skip a slot
11	1601 ft to 3200 ft	Up to 3200 ft	● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2,5)** **or** ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (2.5,5)** **or** ● No restrictions; **stagger rule is (3,5)**	(3,5) or skip a slot NA NA
12	1601 ft to 3200 ft	3201 ft to 4300 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or**	(3.5,6) or skip a slot

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or**	(3,6) or skip a slot
			● Except 160 kt or greater aircraft; **stagger rule is** (3,5) **or**	(3.5,6) or skip a slot
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,6) **or**	NA
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (3,6)	NA
13	1601 ft to 3200 ft	4301 ft to 5700 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2,5) **or**	(3,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or**	(3,6) or skip a slot
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or**	(3.5,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is** (2.5,6) **or**	NA

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
14	1601 ft to 3200 ft	5701 ft to 7400 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5)	(3,6) or skip a slot
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5)	(3,6) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5)	(4,6) or skip a slot
			or	
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6)	NA
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
15	1601 ft to 3200 ft	7401 ft to 9500 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5)	(3.5,6) or skip a slot
			or	

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3.5,6) or skip a slot (3.5,6) or skip a slot NA
16	1601 ft to 3200 ft	9501 ft to 11800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)**	(3.5,7) or skip a slot
17	1601 ft to 3200 ft	11801 ft to 15700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot
18	3201 ft to 4100 ft	Up to 4100 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)** **or** ● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,6)** **or**	(3.5,6) or skip a slot (3.5,6) or skip a slot (3.5,6) or skip a slot (3.5,6) or skip a slot

			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
19	3201 ft to 4100 ft	4101 ft to 4800 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2,5)**	(3.5,6) or skip a slot
			or	
			● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)**	(3.5,6) or skip a slot
			or	
			● Except 160 kt or greater aircraft; **stagger rule is (3,5)**	(3.5,6) or skip a slot
			or	
			● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,6)**	(3.5,6) or skip a slot
			or	
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
20	3201 ft to 4100 ft	4801 ft to 7000 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)**	(3.5,6) or skip a slot
			or	
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)**	(3.5,6) or skip a slot
			or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (2.5,6)**	(3.5,6) or skip a slot
			or	

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	NA
21	3201 ft to 4100 ft	7001 ft to 9100 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; **stagger rule is (3,6)**	(3.5,6) or skip a slot (3.5,6) or skip a slot NA
22	3201 ft to 4100 ft	9101 ft to 11500 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,6)** **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot (5,7) or skip a slot
23	3201 ft to 4100 ft	11501 ft to 15500 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(4,7) or skip a slot
24	4101 ft to 5000 ft	Up to 5000 ft	● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or**	(3.5,6) or skip a slot

			● Except 160 kt or greater aircraft; stagger rule is (3,5) or	(3.5,6) or skip a slot
			● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (2.5,6) or	(3.5,6) or skip a slot
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	NA
25	4101 ft to 5000 ft	5001 ft to 6800 ft	● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	(4.5,6) or skip a slot
			● Except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or	(4.5,6) or skip a slot
			● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2.5,6) or	(4.5,6) or skip a slot
			● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	(4.5,6) or skip a slot
26	4101 ft to 5000 ft	6801 ft to 8900 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	(4,6) or skip a slot
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or	(4,6) or skip a slot

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is** (3,6)	(4,6) or skip a slot
27	4101 ft to 5000 ft	8901 ft to 9100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,5) **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,5) **or** ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance **and** do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is** (3,6)	(4,6) or skip a slot (4,6) or skip a slot (4,6) or skip a slot
28	4101 ft to 5000 ft	9101 ft to 11300 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (2.5,6) **or** ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,6)	(4,7) or skip a slot (4,7) or skip a slot
29	4101 ft to 5000 ft	11301 ft to 15300 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is** (3,6)	(4.5,7) or skip a slot

30	5001 ft to 6400 ft	Up to 6400 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (2.5,5)** **or** ● Except 80 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (2.5,6)** **or** ● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; **stagger rule is (3,6)**	(4.5,6) or skip a slot (4.5,6) or skip a slot (4.5,6) or skip a slot (4.5,6) or skip a slot
31	5001 ft to 6400 ft	6401 ft to 8700 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (3,6)**	(5,6) or skip a slot (5,6) or skip a slot
32	5001 ft to 6400 ft	8701 ft to 15000 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(5,7) or skip a slot
33	6401 ft to 8100 ft	Up to 8100 ft	● Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,5)** **or** ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; **stagger rule is (3,6)**	(5,6) or skip a slot (5,6) or skip a slot
34	6401 ft to 8100 ft	8101 ft to 10300 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; **stagger rule is (3,6)**	(5,7) or skip a slot

35	8101 ft to 8600 ft	Up to 8600 ft	• Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (3,6)	(5.5,6) or skip a slot

to the controllers. The speeds referenced in this table are indicated final approach airspeeds. Guidance concerning "restricted" and "excepted" aircraft is given below.

6. Determine the decision heights for each runway when the glide slope is out of service. Find the larger of the two values. Repeat steps 4 and 5 to determine the DCIA procedure for this runway configuration when either glide slope is out of service.

5.2 AN EXAMPLE OF THE USE OF THE DCIA TABLES

As an example of this process and interpretation of tables 5-1 through 5-3, consider the case of Boston Logan International Airport.

Suppose Boston has three eligible configurations (i.e., there is an ILS or LOC on both runways and the missed approach procedures meet the straight-out criteria), 33L/4R; 15R/4R; and 27/22L. The facility then would go through the exercise of determining the runway lengths to intersection for each configuration and the decisi n heights for (1) when both ILSs are fully available (called "Full ILS" here) and (2) when the glide slopes may be out of service (i.e., localizer only approaches; called "GS out" here)). Having determined these for each configuration, and for each mode (full ILS or GS Out) the facility would then go either to table 5-1, 5-2 or 5-3 depending upon the decision heights, and find the applicable row, as indicated in table 5-4.

Table 5-4. Example of DCIAs at Boston

Runways	Threshold-to-intersection distance (ft)		DHs (ft) (Larger of the two DHs for the two runways)		DCIA Rule (Table-Row)	
	Short	Long	ILS	LOC	Full ILS	GS Out
4R/33L	4144	5201	200	463	(5-1)-21	(5-2)-19
15R/4R	3998	4144	250	562	(5-1)-20	(5-3)-19
27/22L	5979	6744	443	484	(5-2)-25	(5-2)-25

Consider configuration 4R/33L. The decision heights for the two runways for full ILS approaches are both 200 ft. The runway to intersection distances are 4144 and 5201 ft respectively. The DCIA rule for this configuration is therefore found in Row 21 in table 5-1 (i.e., (5-1)-21). Row 21 in table 5-1 provides seven options from which to choose. The facility might choose option number 3, which allows a (2,5)[1] stagger operation with the aircraft 90 kts or less and 160 kts or greater "excepted"[2].

If a glide slope on either runway 4R or 33L were to be out of service, the decision heights for the two runways would be 422 and 463 ft respectively. The larger decision height is 463 ft. The applicable procedure would therefore be found in table 5-2. The runway to intersection distances are, as before, 4144 and 5201 ft respectively. The applicable procedure would therefore be found in row 19 of table 5-2. Row 19 provides 4 options. The facility may determine that it would always use the first option, which allows a (2.5,5) stagger operation and "excepts" aircraft with final approach speeds of 80 kts or less and 160 kts or greater from the (2.5,5) rule.

The facility would identify aircraft groups by types that reflect the appropriate indicated final approach airspeeds. Suppose, for Boston, aircraft with 90 kts or less final approach speeds include all single engine general aviation aircraft, and aircraft with 160 kts or greater final approach speeds include all military fighter-type aircraft. The local order at Boston could then state that the stagger operation for runways (4R/33L) would be conducted with a (2,5) stagger rule, and when either a single engine general aviation aircraft is the leading aircraft, or when a fighter-type aircraft is the trailing aircraft, a DCIA slot shall be missed. If the glide slope to either runway goes out of service, the DCIA operation would be run with a (2.5,5) rule. Again, when either a single engine general aviation aircraft is the leading aircraft, or when a fighter-type aircraft is the trailing aircraft, a DCIA slot shall be missed. The facility would repeat the process for the other two configurations.

To place the results shown in tables 5-1 through 5-3 in perspective, consider the airports listed in table 5-5. These airports are a selection of airports in the top 100 U.S. airports that have converging runways and sufficient instrumentation on those runways to support the DCIA procedure. A plot of these airports on charts shown in figures 5-1 through 5-3. These charts show the extent of each of the "breakpoints" in tables 5-1 through 5-3, respectively. Using the example of Boston again, runway pair 4R/33L has a "shorter distance from

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1 The (2,5) stagger operation requires that aircraft be staggered by 2 nmi when the leading aircraft is a non-heavy aircraft and by 5 nmi when the leading aircraft is a heavy aircraft

2 The simplest way to handle aircraft "excepted" from the DCIA stagger rule is to miss a DCIA slot. "Excepted aircraft" are discussed in section 4.1.

Table 5-5. Some Airports with Potential DCIA Applications*

Airport	Runways	Threshold-to-intersection Distance (ft)		Decision Height (ft)	
		Short	Long	ILS	LOC
SAT	30L/3	0	2,005	200	600
DEN	18/8R	0	17,499	250	335
CLE	23L/28	352	1,859	250	675
PIT	28R/32	553	10,755	200	537
DAY	18/24R	711	1,470	200	421
DTW	27/21L	942	1,276	200	468
MSP	11L/22	996	2,236	250	592
DAY	6L/18	1,470	11,611	200	421
MEM	18L/27	1,750	6,082	200	470
PHL	27R/17	1,871	4,715	250	709
IND	14/23R	2,765	2,789	200	762
IND	14/15L	2,765	7,218	200	423
IND	32/23R	2,789	4,843	200	762
MSP	11R/4	2,813	3,348	200	430
HOU	4/30L	3,050	4,375	250	453
STL	30R/24	3,141	9,339	250	466
DAY	18/24L	3,245	7,455	200	421
SFO	19L/28R	3,296	4,895	200	449
BDL	6/33	3,348	4,837	250	586
BOS	15R/4R	3,998	4,144	250	562
SFO	19L/28L	4,050	4,870	200	450
BOS	33L/4R	4,144	5,201	200	463
BWI	28/33L	4,278	4,739	200	378
MSP	29L/22	4,454	6,653	250	592
CVG	18R/27	4,502	5,213	200	365
DEN	17L/26L	4,618	20,901	200	467
STL	30L/24	4,648	8,409	250	466
BWI	15R/10	4,709	5,238	200	436
BDL	24/33	4,837	6,155	250	350
IND	32/5L	4,843	7,218	200	388
MKE	7R/1L	4,861	5,815	200	457
DEN	17L/8R	5,408	20,920	250	335
CLT	5/36R	5,681	5,705	200	404
DTW	27/21R	5,894	7,966	200	468
PHL	9R/17	6,125	13,793	250	709
ORD	14R/22R	6,173	9,479	200	528
ORD	4R/9R	7,662	11,016	200	599
IAH	32R/27	7,753	15,397	200	373
IAD	12/19R	9,272	13,082	200	469
ORD	32L/27R	9,886	9,983	200	406
IAD	12/19L	10,013	16,381	200	469
DFW	18R/13R	10,275	13,264	200	509
DFW	35R/31R	10,955	13,671	200	457
IAH	32R/26	11,381	14,267	200	404
ORD	9R/14L	11,739	15,865	200	488
ORD	22R/27L	12,006	13,483	200	528
DFW	17L/13R	20,367	26,619	200	509
DFW	36L/31R	22,494	23,405	200	457

* Ordered by the shorter distance to intersection

threshold-to-intersection" of 4144 feet and a "longer distance from threshold-to-intersection" of 5201 feet. With a decision height of 200 feet the procedure defined in table 5-1 would be appropriate. Therefore, the chart in figure 5-1 would have a point at 4144/5201 for Boston 4R/33L. As one can see from figure 5-1, about one half of the runway configurations on the list in table 5-5 are covered by the (2,5) stagger rule, with the appropriate restrictions depending on which "box" the runway configuration falls within. There are a few runway configurations that fall outside all of the "boxes". This means that even a (3,6) stagger rule will not be sufficient to cover these runway configurations using the conservative analysis assumptions. Figures 5-2 and 5-3 show the same type of data for those configurations with decision heights of 250 to 500 feet and 500 to 700 feet, respectively.

5.3 RESULT SENSITIVITIES

The original model uses an instantaneous speed increase to a higher constant missed approach speed to model the trailing aircraft's acceleration during its missed approach maneuver. The second order model uses a constant acceleration during the missed approach maneuver. Upper bounds of maximum possible differences in separation between the two models were used to evaluate model sensitivity to the assumption of an instantaneous speed increase. For operations in which neither approach decision height exceeded 250 feet, the second order model was used to determine DCIA procedure restrictions. These results were compared with those of the original model. The next two subsections discuss the results of an evaluation of the stability of the numerical calculation and the difference in the DCIA procedure restrictions.

5.3.1 Evaluation of Stability of the Numerical Calculations

Two aspects of the stability of the original model's numerical calculations were evaluated:

a. Sensitivity of computations to the computer and the software used to implement the model

b. Sensitivity of the original model to the assumption of constant trailer missed approach speed of the trailing aircraft

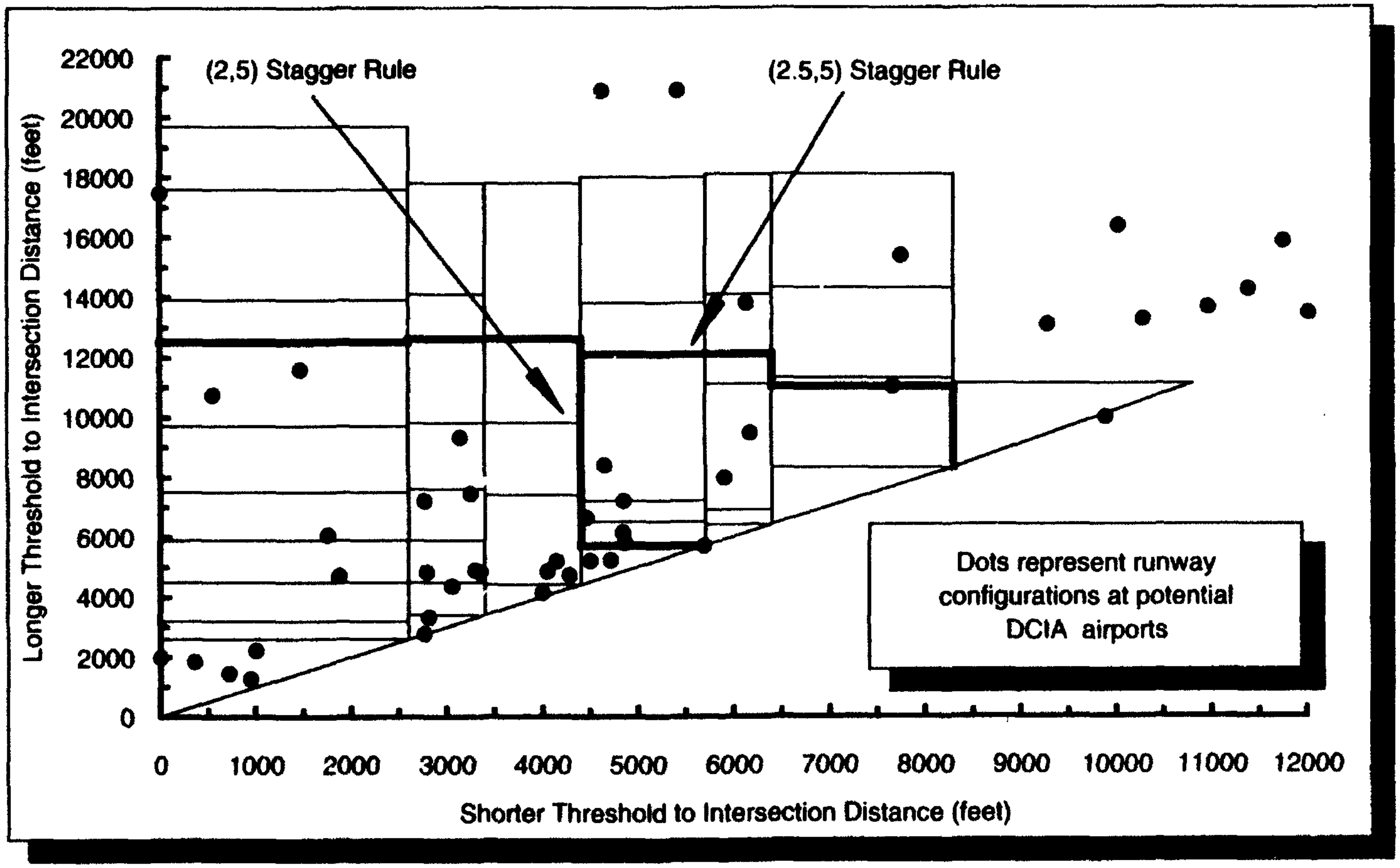

Figure 5-1. DCIA Procedure Regions for Decision Heights < = 250 Feet

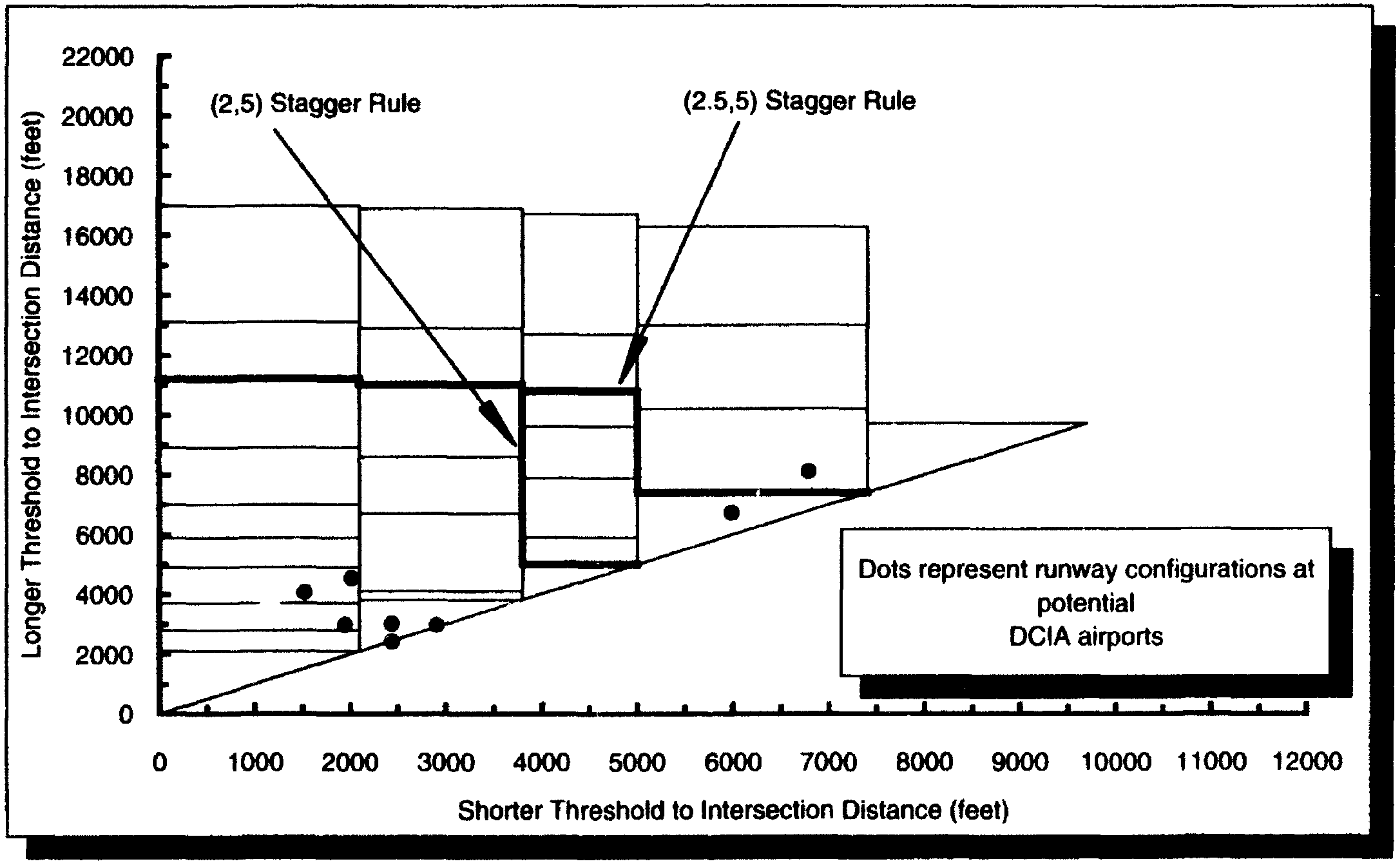

Figure 5-2. DCIA Procedure Regions for Decision Heights > 250 feet and < = 500 Feet

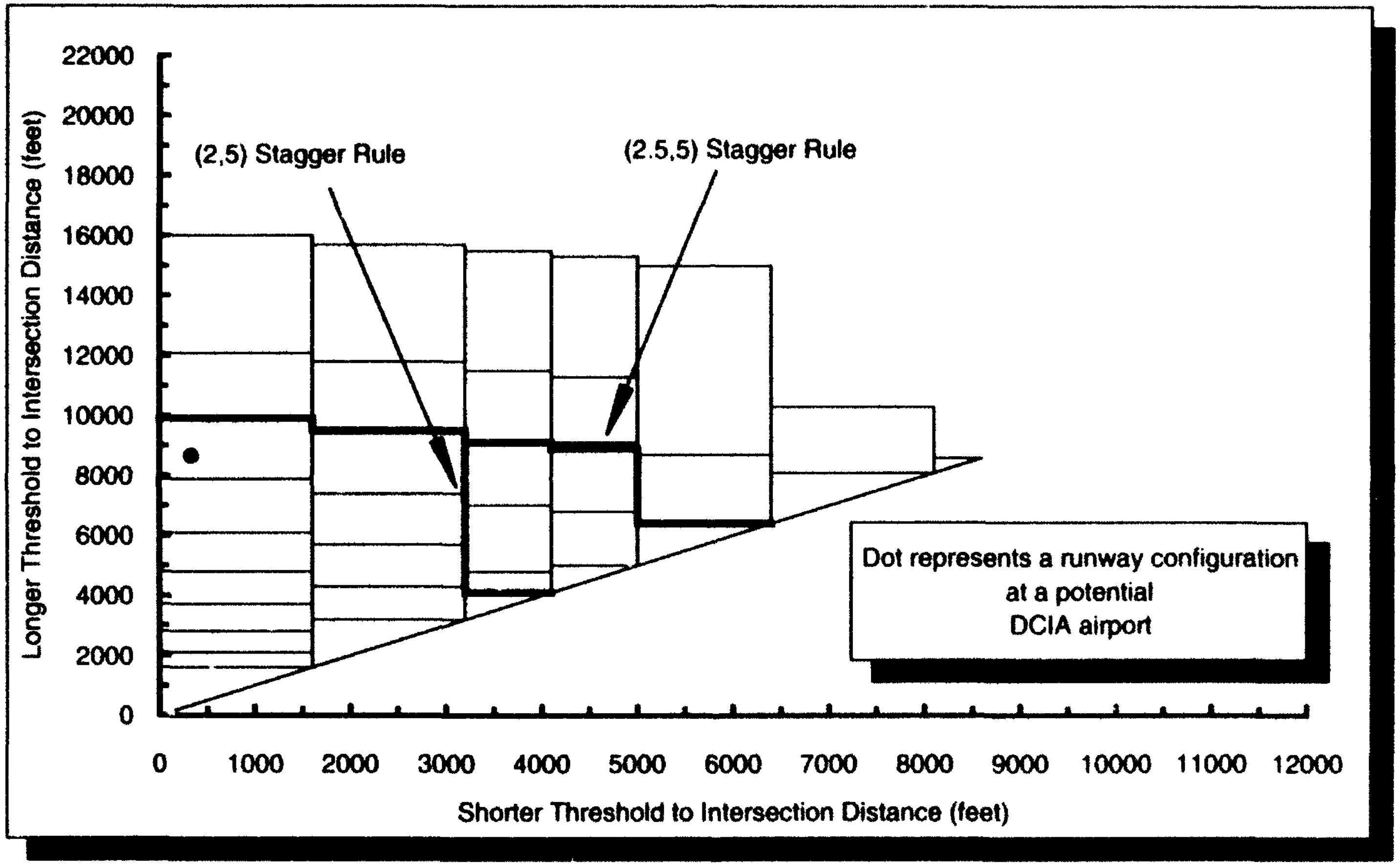

Figure 5-3. DCIA Procedure Regions for Decision Heights > 500 feet and < = 700 Feet

The original model was implemented in Microsoft[3] Excel on both an IBM PC and a Macintosh and the numeric output of the two implementations was compared. The two Excel model implementations were found to be in close agreement. Also, the original model implemented on the Macintosh in Excel and the second order model implemented on the Macintosh in Mathematica were compared for a variety of cases. The two models' time separations consistently differed by less than 0.01 seconds and, in all cases in which the trailing aircraft had not reached its missed approach point when the leading aircraft reached the intersection, the distance separations differed by much less than 0.001 nmi.[4] This consistency is expected: in the second order model, the constant acceleration is chosen so that aircraft will reach the intersection at the same time in both models; and the two models are designed to be the same until the trailing aircraft begins its missed approach maneuver.

As explained in section 4.2, after the trailing aircraft begins its missed approach maneuver, the separation computed by the second order model is larger than that of the original model (assuming the trailing aircraft has not passed the lead aircraft). Theoretical bounds on the maximum possible differences in separation between the two models were determined as described in appendix E. These theoretical bounds are presented in figures E-1 to E-6. For eight specific cases in which the trailing aircraft had begun its missed approach maneuver, table E-2 provides a detailed comparison of the differences in separation computed by the two models versus the theoretical bounds on those differences. This comparison is summarized in table 5-6. The "Observed Difference" is the difference in separation distances measured by the two models when the leading aircraft is at the intersection. The various observed differences result from a leading aircraft with nominal 80 kt final approach airspeed and three different trailing aircraft with nominal final approach airspeeds of 150, 160, and 170 kts, respectively. For each trailing aircraft, cases corresponding to different wind conditions and threshold-to-intersection distances are presented.

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3 Microsoft is a registered trademark of the Microsoft Corporation, IBM is a registered tradmark of the International Business Machines Corporation. Macintosh is a registered trademark of Apple Computer, Incorporated, and Mathematica is a registered trademark of Wolfram Research, Inc.

4 The difference in time for leading and trailing aircraft to reach the intersection of the runway centerlines is called *time separation*. The distance between the two aircraft when the leading aircraft is at the intersection is called *distance separation*, or simply *separation*.

Table 5-6. Some Differences in Aircraft Separation Distances for the Original and Second Order Models

Final Approach Airspeed of Trailing Aircraft (kts)	Theoretical Bound on Difference (ft)	Observed Difference (ft)
150	180	21
160	229	32
	272	150
	316	50
170	230	107
	267	22
	269	225
	313	153

5.3.2 Corroboration of DCIA Procedure Restrictions

In order to corroborate the procedure restrictions generated using the original model and to partially evaluate the sensitivity of DCIA procedures to the assumption of constant missed approach speed, the second order model was used to generate DCIA procedure restrictions. The set of DCIA operations chosen for the comparative analysis was all operations in which neither approach decision height exceeded 250 feet.

The following methodology was used. Let D1 and D2 be the shorter and longer threshold-to-intersection distances of the two approach paths, respectively. The rows of table 5-1 are uniquely specified by (D1, D2) pairs. Each row is called a *box* because the rows determine the rectangles shown in figure 5-1. The second order model was used to try to increase the value of D2 for each box in table 5-1. The requirement imposed on the second order model-generated DCIA procedures was that in each box, restrictions for the minimum stagger requirements could be weakened but not strengthened. No requirement was placed on restrictions for other staggers in each box. For example, in box 7 of table 5-1, only the restriction for the (2,5) stagger rule cannot be strengthened using the second order model. The results of this analysis are presented in table G-1 in appendix G. Table G-1 is a reproduction of table 5-1 with a column substituted for the right hand column in that table to show the results of the second order model analysis. Note, for example, that in box 7 of table G-1, the second order model results in the same restriction for the (2,5) stagger, but the rules based on the original model for the other staggers do not suffice for the D2 value determined using the second order model.

The original model was implemented in Microsoft[3] Excel on both an IBM PC and a Macintosh and the numeric output of the two implementations was compared. The two Excel model implementations were found to be in close agreement. Also, the original model implemented on the Macintosh in Excel and the second order model implemented on the Macintosh in Mathematica were compared for a variety of cases. The two models' time separations consistently differed by less than 0.01 seconds and, in all cases in which the trailing aircraft had not reached its missed approach point when the leading aircraft reached the intersection, the distance separations differed by much less than 0.001 nmi.[4] This consistency is expected: in the second order model, the constant acceleration is chosen so that aircraft will reach the intersection at the same time in both models; and the two models are designed to be the same until the trailing aircraft begins its missed approach maneuver.

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The following methodology was used. Let D1 and D2 be the shorter and longer threshold-to-intersection distances of the two approach paths, respectively. The rows of table 5-1 are uniquely specified by (D1, D2) pairs. Each row is called a *box* because the rows determine the rectangles shown in figure 5-1. The second order model was used to try to increase the value of D2 for each box in table 5-1. The requirement imposed on the second order model-generated DCIA procedures was that in each box, restrictions for the minimum stagger requirements could be weakened but not strengthened. No requirement was placed on restrictions for other staggers in each box. For example, in box 7 of table 5-1, only the restriction for the (2,5) stagger rule cannot be strengthened using the second order model. The results of this analysis are presented in table G-1 in appendix G. Table G-1 is a reproduction of table 5-1 with a column substituted for the right hand column in that table to show the results of the second order model analysis. Note, for example, that in box 7 of table G-1, the second order model results in the same restriction for the (2,5) stagger, but the rules based on the original model for the other staggers do not suffice for the D2 value determined using the second order model.

Based on the theoretical comparison of the original model and the second order model, it is clear that for every box in table G-1, D2 for the second order model must be at least as large as that for the original model. Examination of table G-1 shows this to be the case. The increase in D2 value of the second order model over that of the original model ranges from 0 to 3900 feet. Table 5-7 shows the largest increases in D2 achieved by the second order model. Typical increases are about 100 to 200 feet. Even where there are no increases in D2, operational restrictions are often less restrictive using the second order model. In all cases, the increase in D2 using the second order model is within the theoretical bounds discussed in the previous subsection.

Table 5-7. Largest Increases in D2 Between the Original and Second Order Models for Decision Heights <=250 ft

Box Number	D1	Original D2	Second Order Model D2	Delta D2
7	2600	10600	12500	1900
21	4400	5800	7400	1600
25	4400	13900	17800	3900
40	8300	8700	11000	2300

Figure 5-4 presents the boxes generated using the second order model for decision heights of 250 feet or less. Comparison with figure 5-1, which presents the boxes generated using the original model for decision heights of 250 feet or less, shows that the gains in D2 values achieved using the second order model rather than the original model are usually modest, but in some cases (e.g., those configurations identified in table 5-7) the gains are significant.

5.4 ANALYSIS OF PARTICULAR SITES

The procedures that are listed in tables 5-2, 5-3, and 5-4 can be safely applied to any runway configuration that conforms to the requirements in the tables. The analysis from which these tables were developed insures that a minimum horizontal and time separation are maintained at the intersection of the converging runways in the event of consecutive missed approaches. However, because the procedures are categorized by ranges of values of the parameters, the separation between aircraft executing consecutive missed approaches at certain runway configurations will be greater than the required minimum separation. In particular, if the runway configuration is in the lower left corner of any of the cells in figures 5-1, 5-2, or 5-3

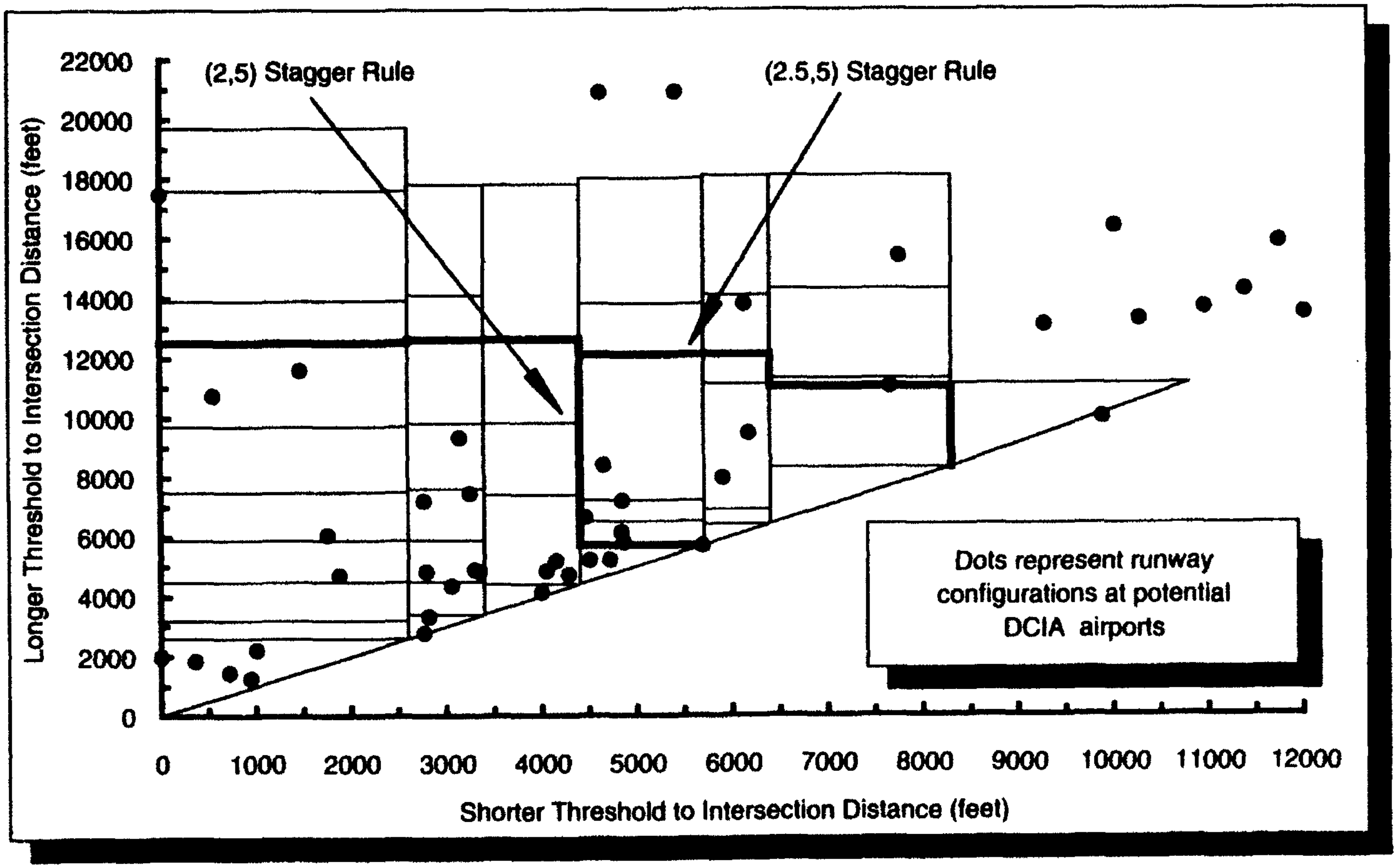

Figure 5-4. DCIA Procedure Regions for Decision Heights of 250 Feet or Less Using the Second Order Model

Except 90 kt or less aircraft **and** except 160 kt or greater aircraft; stagger rule is (3,5),
or
Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 90 kt or less aircraft; stagger rule is (3,5).

Notably pairings of jets (120/150) do not yield predicted separations greater than 1 nmi at stagger values of 2 or 2.5 nmi. Applying the DCIA procedure with a 3 nmi stagger requirement may not prove to be a beneficial operation at ORD.

Using the site specific runway lengths, included angle of 50 degrees and decision height of 200 ft, the pairing of jets at stagger values below 3 nmi is no problem for the non-heavy leading case. Using a 2.5 nmi stagger, the predicted separation for the 120/150 pairing is 1.59 nmi for the slow non-heavy aircraft leading. For the case of heavy leading, a 5 nmi stagger yields an acceptable separation of 84 seconds. Applying the (2.5,5) rule to all other speed pairings leads to a general statement of a site specific procedure:

Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 100 kt or less aircraft; stagger rule is (2.5,5).

The important difference between this procedure and the one in table 5-1 is the lower stagger values allowed for the pairing of jets. (In this case, the second order model was not required to yield the improvement. The near optimal included angle and the tailoring of runway lengths gives a dramatic improvement).

An even more dramatic improvement can be realized for jets by stating the procedure as a (2,5) rule. It does lead to more significant restrictions, however, on other (slower) aircraft. Applying the (2,5) rule to all other speed pairings leads to a general statement of a possible site specific procedure:

Do not pair 120 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 110 kt or less aircraft; stagger rule is (2,5).

If the traffic is predominately comprised of jets this is a very efficient stagger operation.

5.4.2.2 PHL 9R/17

Philadelphia (PHL) is chosen to illustrate a case of asymmetric runway lengths. For the configuration PHL 9R/17 the lengths from threshold to intersection are 13,793 and 6,125 feet feet, respectively. The applicable rule in table 5-1 is found in row 37. It calls for at least 2.5 nmi stagger for the non-heavy leading case with the following restrictions:

> Restrict 110 kt or less aircraft to the runway with the shorter threshold-to-intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; stagger rule is (2.5,6).
>
> **or**
>
> Restrict 110 kt or less aircraft to the runway with the shorter threshold to interesection distance **and** do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing **and** except 80 kt or less aircraft; stagger rule is (3,6).

Because of the significant asymmetry, the minimum (single) stagger value must work for the worst case of a leading aircraft on the long runway. As indicated above, 2.5 nmi stagger is required. Consider the case of pairing jet traffic (as typified by the 120/150 pairing in the DCIA model). For this case, when the slow aircraft (120 KIAS) is leading on the long runway (9R in Philadelphia) a predicted separation of 1.06 nmi is found. When the slow aircraft is leading on the short runway (17) a predicted separation of 1.74 nmi is found when using the same 2.5 nmi stagger. This result begs the question of whether a lower stagger value could be safely employed when the slow aircraft is leading on the short runway. A site specific analysis shows that a 2.0 nmi stagger is sufficient for that case (the predicted separation is 1.15 nmi). An asymmetric stagger may be beneficial. Applying a "(2.0&2.5,6)" stagger rule to all other speed pairings leads to a general statement of a possible site specific procedure. The site specific decision height is 250 feet. Using the site specific runway lengths, included angle of 83 degrees and decision height of 250 ft, a site specific analysis using asymmetric stagger shows the following result.

> Restrict 100 kt or less aircraft to the runway with the shorter threshold-to-intersection distance **and** except 90 kt or less aircraft **and** except 160 kt or greater aircraft; stagger rule is (2.0&2.5/6).

In this case, the removal of the 110 kt restriction requires the application of the second order model. The important point in this example is that a lower effective stagger value can be safely used which could result in higher arrival rates.

SECTION 6

RECOMMENDATIONS

6.1 RECOMMENDATIONS FOR IMPLEMENTATION

The DCIA procedure as discussed in this document is capable of supporting the DCIA concept in the current ATC environment and available technology. The tables in section 5 define the stagger values and conditions under which the DCIA procedure can be safely conducted. Although the categorization found in the tables in section 5 is not unique, it is a scheme that is designed for ease of use by the various facilities that wish to implement the procedure. For this reason we recommend that the implementation of the DCIA procedure through an FAA order be based on these tables.

Because of the conservative nature of the results in section 5, some of the facilities might suffer unneeded restrictions based on the tables. As shown in the examples in section 5.4, an airport may benefit from an analysis of its particular configuration rather than basing the procedure on the worst case facility in its group of airports. Therefore, we recommend that at those airports with significant traffic levels or with other unique considerations (e.g., the runway with the shorter threshold-to-intersection distance is really the airport's main runway) a site specific analysis should be performed and the procedure at that facility be based on the results of that analysis.

6.2 RECOMMENDATIONS FOR FUTURE WORK

The procedure as discussed in this document is designed to be simple for easy operational use in the current system. It contains several restrictions that were considered necessary for a first step. Many of the constraints make the procedure conservative, and enhancements are possible to make it more efficient or applicable to more geometries without compromising the safety of its operation. Such enhancements will need further research and study, and in some cases will require additional prototyping and simulations to determine their viability. This section lists some areas of such possible enhancements.

a. DCIAs for non-precision approaches

b. Site specific variable and asymmetric stagger values

c. Procedure based on speed differences

d. Turning missed approaches

e. Goal-based procedure

f. Role of cockpit traffic display

g. Risk analysis

These are discussed in turn.

6.2.1 Non-Precision Approaches

The DCIA procedure discussed in this report requires straight-in precision (instrument landing system (ILS) or microwave landing system (MLS)) approaches or straight-in localizer approaches. There are many configurations at top U.S. airports where some runways are not equipped with such approaches where the use of DCIAs could facilitate capacity benefits. An analysis of DCIAs for very high frequency omnidirectional range (VOR) approaches, ILS back course approaches, and flight management system (FMS)/area navigation (RNAV) approaches should be conducted to determine the possibility of extending the DCIA procedure to non-precision approaches.

6.2.2 Asymmetric Stagger

The stagger requirements for a given runway geometry depend strongly on the length of the runway to intersection that the slower aircraft must travel. Slow aircraft leading on a runway with the longer distance to intersection requires larger stagger values for safe separation at intersection than a faster aircraft destined for a runway with a shorter distance to intersection. Many runway configurations consist of runways of significantly unequal lengths from the runway threshold to the intersection point. Thus, for a stream of aircraft with significant difference in approach speeds, the stagger required (to assure a required separation at the intersection in the event of consecutive missed approaches) between a slow leading aircraft and a faster following aircraft may be larger than 2 nmi, while the stagger required between that faster aircraft and a next slower trailing aircraft may be less than 2 nmi. Rather than using the larger of the two stagger values at all times as in the DCIA procedure described in this document a stagger value based on the speed differences and runway lengths may provide a capacity benefit. Operationally, this may be facilitated by rules such as placing an aircraft off-center between two ghost targets to provide the required unequal stagger values, or possibly by providing "target ghosts".

An important consideration here is also the minimum acceptable stagger value. The 2 nmi minimum in the current procedure assures at least 2 nmi in space separation for airborne

aircraft for all converging geometries. However, a 2 nmi stagger value is not always necessary to assure 2 nmi in space. For example, when an aircraft on the runway with the longer distance from threshold-to-intersection is leading, a stagger less than 2 nmi may assure at least 2 nmi in space at all times. Different stagger values (i.e., asymmetric stagger) depending upon which runway has the leading aircraft may facilitate smaller stagger requirements and thus provide greater capacity benefits.

6.2.3 Procedure by Speed Difference

Speed differences in aircraft landing on the converging runways is a key factor in determining what stagger value is necessary to achieve safe separation at the intersection. The DCIA procedure analyzed in this document aims at using one stagger value for all aircraft pairs. It may be possible to develop a procedure where the required stagger depends upon the expected difference between the landing speeds of the converging aircraft. Sites with geometries with very long distances to the intersection that have a negligible percentage of traffic exhibiting large speed differences may be able to benefit from such a procedure. The challenge in the design of such a procedure would be to make it simple enough to be operationally viable.

The current procedure utilizes expected airspeeds as the basis for the analysis and considers worst winds and geometries to determine the effect on the expected separation. Since it is the ground speeds that affect the separation achieved, consideration may be given to designing a procedure based on ground speeds. A critical factor in the design of such a procedure would be its implications on controller workload, since it implies required controller monitoring of ground speeds.

6.2.4 Turning Missed Approaches

The current procedure utilizes straight-out missed approaches. The design of such a procedure is not possible at some sites due to terrain, airspace, or environmental considerations. Consideration should be given to utilizing vector based turning missed approaches in DCIAs.

Some sites (e.g., DFW and ORD) have a potential of using three runways where two runways are parallel and one is converging. Turning missed approaches for the DCIA procedure may facilitate the maintenance of the independence of one parallel approach, with dependent converging approaches to the other parallel and the converging runway.

6.2.5 Goal Based Procedure

The analysis presented in this paper is aimed at specifying the minimum stagger value that a controller must provide so that even in the worst cases of winds, aircraft speed differences and loss of either radio or radar, the two aircraft will be separated in the event of a consecutive missed approach. The procedure is thus very conservative for most cases. Paragraph 6-64 of FAA Order 7110.65 establishes how controllers may adjust separation required to account for differences in speeds and winds. It is conceivable that the DCIA procedure be formulated in terms of the expected separation at the intersection in the event of consecutive missed approaches and that controllers would adjust the stagger separation required at the threshold in order to deliver such a separation. A goal-oriented procedure would give controllers the flexibility to provide more efficient spacing when the conditions are not extreme, (e.g., when approach speeds of the two converging aircraft do not differ by 60, 70 or 80 knots or when winds are not 30 knots). The issues that must be addressed in such a formulation is whether controllers would be able to conduct such an operation when the separation event being posited is a rare event. It would also need to address radar and ghost target availability requirements over the runways.

An analysis of separations achieved for different ground speeds may be provided as guidance to controllers.

6.2.6 Role of Cockpit Traffic Display

The DCIA procedure aims at separation in the event of consecutive missed approaches. If a traffic display such as a TCAS traffic display should prove to be capable of allowing pilots to provide self-separation on final approach, then a possibility exists of designing a DCIA procedure such that once established on final approach, the trailing aircraft may be cleared for a converging approach to maintain a certain stagger distance from the leading aircraft. The cockpit traffic display may have to be capable of showing appropriate ghost targets for such a procedure.

6.2.7 Risk Analysis

As discussed in section 3.3.7 the sequence of events leading to a worst case consecutive missed approach are, when taken together, extemely unlikely. In the future, after additional experience has been gained using the DCIA procedure as discussed in this paper, there may be some justification for and interest in relaxing some of the constraints placed on the model that was used to generate tables 5-2, 5-3, and 5-4 in order to create a more efficient procedure. A risk analysis of the consecutive missed approach issue can be made which will allow decision makers to evaluate the operation with respect to the risks involved. Such a study would also, presumably, make the program easier to sell to the users.

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APPENDIX A

EQUATIONS OF MOTION

The following discussion describes the missed approach dynamics that are used in the DCIA model. The points along the approach where significant events happen as an aircraft executes a missed approach are shown in figure A-1. The aircraft is assumed to fly over the outer marker on the approach path to the runway at a given speed. The outer marker is at a distance of OM from the intersection. After flying over the outer marker, the aircraft slows to its final approach airspeed as it descends on the glide slope. The deceleration is assumed to take place over a given distance and the final approach airspeed is reached at a distance DP from the intersection. The final approach airspeed is maintained until the missed approach point which is at a distance MAP from the intersection. At the missed approach point, the aircraft instantaneously increases its speed. The aircraft then flies straight down the runway and through the intersection.

In analyzing the dynamics of a pair of aircraft executing missed approaches on converging runways, the starting positions of the aircraft have to be such that the proper stagger distance would have been achieved had the leading aircraft actually made it to the runway threshold. Since it is assumed for this analysis that the leading aircraft does not accelerate, there is no loss of generality in letting the leading aircraft start at its runway threshold at time $t=0$.

Since the separation at the intersection is measured as a time separation if the leading aircraft is a heavy aircraft and as a distance separation if the leading aircraft is a non-heavy aircraft, two sets of equations will be developed.

A.1 HEAVY LEADING CASE

The object of this analysis is to compute the difference in time between the leading and trailing aircraft passing over the runways centerline intersection.

If the distance from the threshold to the intersection for the leading aircraft's runway is D_L (nmi) then the minimum distance to the intersection for the trailing aircraft when the leading aircraft is at its runway threshold (and hence the worst situation) would be D_L+S, where S (nmi) is the required stagger distance. See figure A-2.

Regardless of where the trailing aircraft is, it takes a time D_L/M_L for the leading aircraft to reach the intersection where M_L is the missed approach ground speed of the leading aircraft.

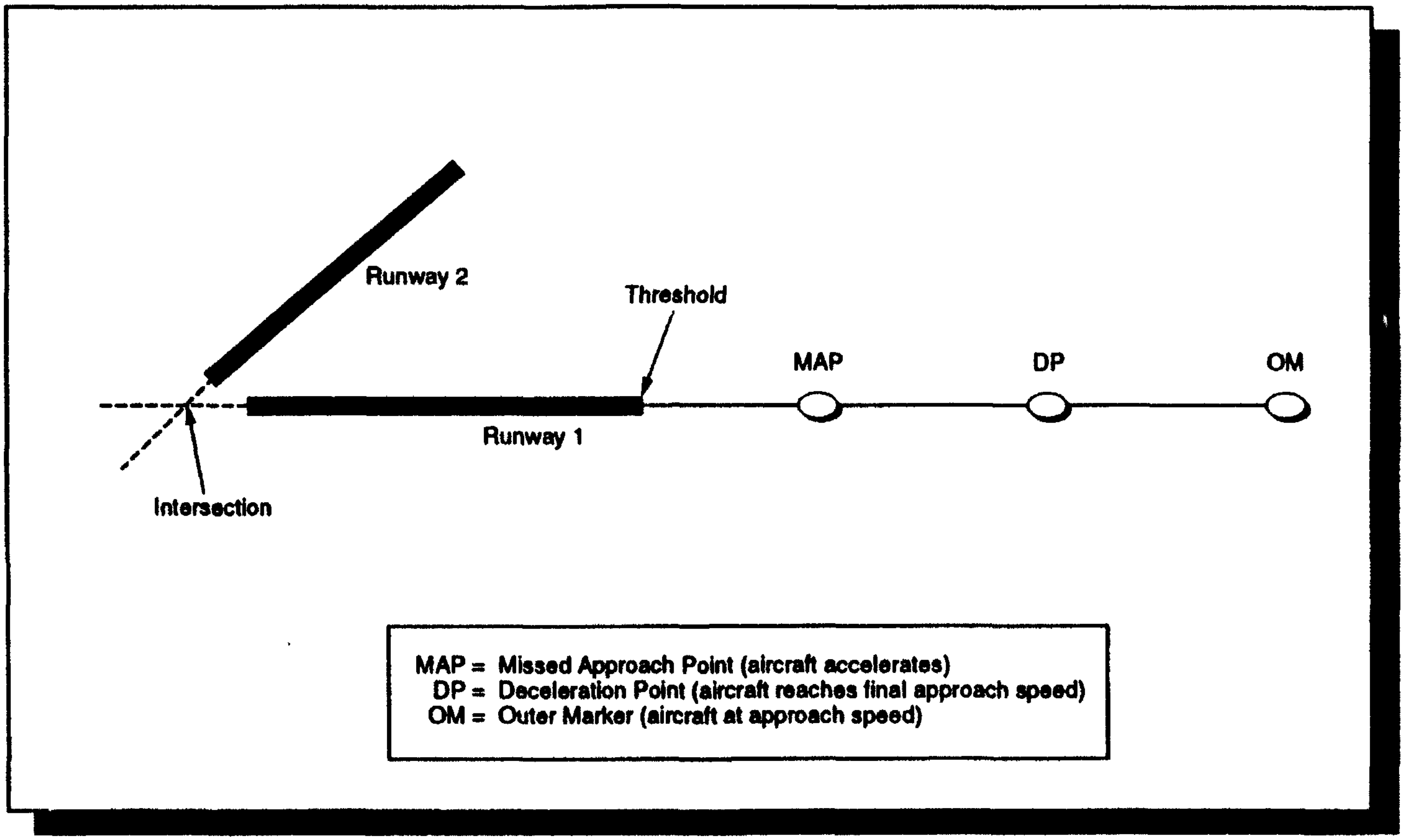

Figure A-1. Missed Approach Geometry

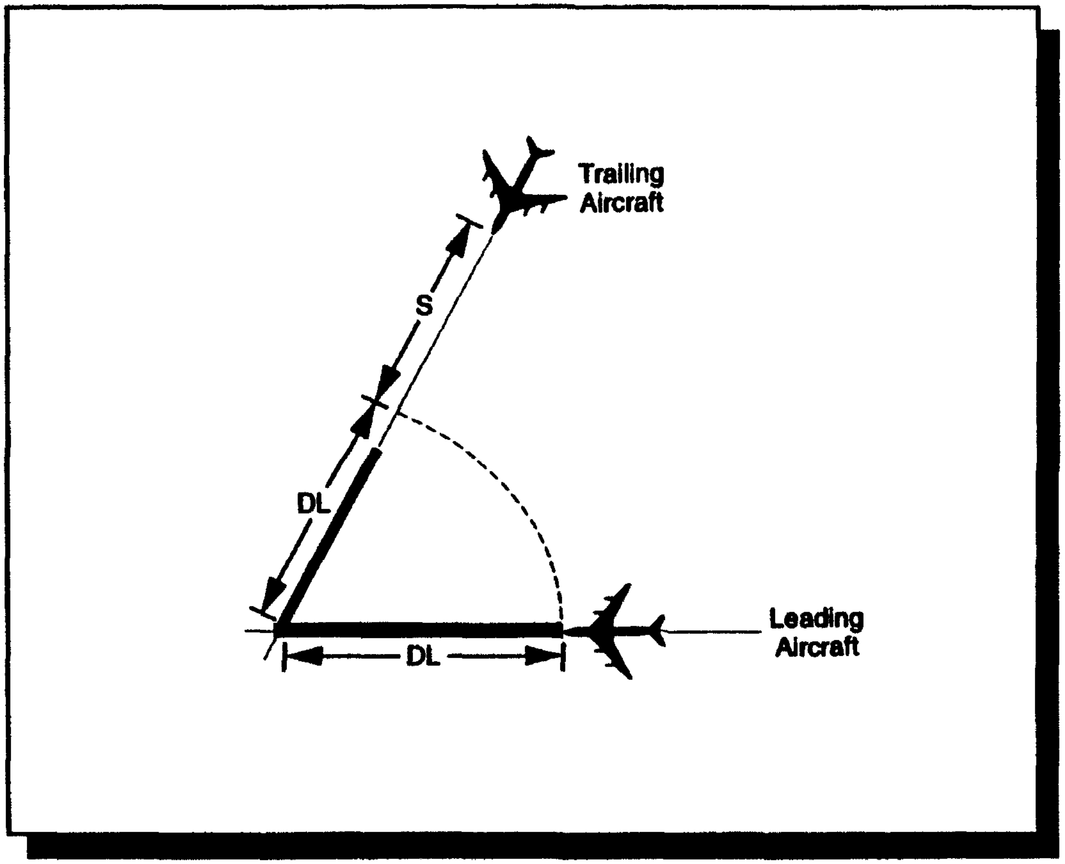

Figure A-2. Stagger Geometry

The time it takes the trailing aircraft to reach the intersection depends where on its approach the trailing aircraft is when the leading aircraft is at its runway threshold. The trailing aircraft can be outside its outer marker (i.e., the aircraft is farther from the intersection of the runways than the outer marker is from the intersection), inside its outer marker but still decelerating, outside its missed approach point but flying at its final approach speed, or inside its missed approach point. For each of these cases, the following expressions have been developed for the time separation, t, between the leading and trailing aircraft at the intersection.

If the trailing aircraft is outside its outer marker:

$$\text{if } (D_L + S) \geq OM_T$$

$$t = \frac{D_L + S - OM_T}{G_T} + \frac{2 \times (OM_T - DP_T)}{G_T + F_T} + \frac{DP_T - MAP_T}{F_T} + \frac{MAP_T}{M_T} - \frac{D_L}{M_L} \tag{1}$$

If the trailing aircraft is inside its outer marker and is still decelerating:

$$\text{if } DP_T \leq (D_L + S) < OM_T$$

$$t = \frac{2 \times (OM_T - DP_T) \times \left(F_T - \sqrt{\dfrac{F_T^2 - (D_L + S - DP_T) \times (F_T^2 - G_T^2)}{OM_T - DP_T}} \right)}{F_T^2 - G_T^2} + \frac{DP_T - MAP_T}{F_T} + \frac{MAP_T}{M_T} - \frac{D_L}{M_L} \tag{2}$$

If the trailing aircraft is outside its missed approach point but is at its final approach speed:

$$\text{if } MAP_T \leq (D_L + S) < DP_T$$

$$t = \frac{D_L + S - MAP_T}{F_T} + \frac{MAP_T}{M_T} - \frac{D_L}{M_L} \tag{3}$$

If the trailing aircraft is inside its missed approach point:

$$\text{if } (D_L + S) < MAP_T$$

$$t = \frac{D_L + S}{M_T} - \frac{D_L}{M_L} \tag{4}$$

where

t	=	the time separation at the intersection
D_L	=	the leading aircraft's threshold-to-intersection distance
S	=	the stagger distance
OM_T	=	the trailing aircraft's outer marker to intersection distance
DP_T	=	the trailing aircraft's point of decelertion to intersection distance
MAP_T	=	the trailing aircraft's miss approach point to intersection distance
	=	$D_T + (DH - 50)/(6076 \times \tan(3^o))$
D_T	=	the trailing aircraft's threshold-to-intersection distance
DH	=	the decision height
G_T	=	the trailing aircraft's ground speed outside its outer marker
F_T	=	the trailing aircraft's final approach ground speed
M_T	=	the trailing aircraft's missed approach ground speed
M_L	=	the leading aircraft's missed approach ground speed

Note that in equation (2) F_T and G_T must be different or else the evaluation of the equation is not possible. In other words, it is assumed that the trailing aircraft decelerates from its outer marker speed to its final approach speed.

A.2 NON-HEAVY LEADING CASE

The case where the leading aircraft is a non-heavy is more complex because not only does the separation at the intersection depend on where the trailing aircraft is when the leading aircraft is at its runway threshold, but the separation also depends on where the trailing aircraft is when the leading aircraft is at the intersection. The trailing aircraft can be in any of the four locations at the start (i.e., outside its outer marker, inside its outer marker but decelerating, outside its missed approach point but flying at its final approach speed, or inside its missed approach point) and end up at any of those four locations plus any of the locations inside of its starting location (i.e., closer to the runway intersection). Therefore there are 10 cases which have to be considered.

If the trailing aircraft starts inside its missed approach point and, obviously, ends up inside its missed approach point:

$$\text{if } (D_L + S) \le MAP_T$$

$$sep = D_L + S - \frac{M_T \times D_L}{M_L} \qquad (5)$$

If the trailing aircraft starts outside it missed approach point flying at its final approach speed and ends up outside its missed approach point:

$$
\begin{aligned}
&\text{if } MAP_T < (D_L + S) \le DP_T \\
&\text{and} \\
&\text{if } (D_L + S - MAP_T)/F_T \ge D_L / M_L \\
&sep = D_L + S - \frac{F_T \times D_L}{M_L}
\end{aligned}
\qquad (6)
$$

If the trailing aircraft starts outside its missed approach point flying at its final approach speed and ends up inside its missed approach point:

$$
\begin{aligned}
&\text{if } MAP_T < (D_L + S) \le DP_T \\
&\text{and} \\
&\text{if } (D_L + S - MAP_T)/F_T < D_L / M_L \\
&sep = MAP_T - M_T \times \left(\frac{D_L}{M_L} - \frac{D_L + S - MAP_T}{G_T} \right)
\end{aligned}
\qquad (7)
$$

If the trailing aircraft starts inside its outer marker and is decelerating and ends up inside its outer marker and is decelerating:

$$
\begin{aligned}
&\text{if } DP_T < (D_L + S) \le OM_T \\
&\text{and} \\
&\text{if } \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} \ge \frac{D_L}{M_L} \\
&sep = D_L + S - \left(\sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S)} \times \frac{D_L}{M_L} + A \times \left(\frac{D_L}{2 \times M_L} \right)^2 \right)
\end{aligned}
\qquad (8)
$$

If the trailing aircraft starts inside its outer marker and is decelerating and ends up outside its missed approach point at its final approach speed:

$$\text{if } DP_T < (D_L + S) \le OM_T$$

and

$$\text{if } \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} < \frac{D_L}{M_L}$$

and

$$\text{if } \left(\frac{DP_T - MAP_T}{F_T} + \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} \right) \ge \frac{D_L}{M_L}$$

$$sep = DP_T - F_T \times \left(\frac{D_L}{M_L} - \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} \right) \qquad (9)$$

If the trailing aircraft starts inside its outer marker and is decelerating and ends up inside its missed approach point:

$$\text{if } DP_T < (D_L + S) \le OM_T$$

and

$$\text{if } \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} < \frac{D_L}{M_L}$$

and

$$\text{if } \left(\frac{DP_T - MAP_T}{F_T} + \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} \right) < \frac{D_L}{M_L}$$

$$sep = MAP_T - M_T \times \left(\frac{D_L}{M_L} - \frac{F_T - \sqrt{G_T^2 + 2 \times A \times (OM_T - (D_L + S))}}{A} - \frac{DP_T - MAP_T}{F_T} \right) \qquad (10)$$

If the trailing aircraft starts outside its outer marker and ends up outside its outer marker:

$$\text{if } OM_T < (D_L + S)$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T}\right) \geq \frac{D_L}{M_L} \tag{11}$$

$$sep = D_L + S - G_T \times \frac{D_L}{M_L}$$

If the trailing aircraft starts outside its outer marker and ends up inside its outer marker and is still decelerating:

$$\text{if } OM_T < (D_L + S)$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T}\right) \geq \frac{D_L}{M_L}$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T} + 2 \times \frac{OM_T - DP_T}{F_T + G_T}\right) \geq \frac{D_L}{M_L}$$

$$sep = OM_T - \left(G_T \times \left\{\frac{D_L}{M_L} - \frac{D_L + S - OM_T}{G_T}\right\} + \frac{A}{2} \times \left\{\frac{D_L}{M_L} - \frac{D_L + S - OM_T}{G_T}\right\}^2\right) \tag{12}$$

If the trailing aircraft starts outside its outer marker and ends up outside its missed approach point and is at its final approach speed:

if $OM_T < (D_L + S)$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T}\right) < \frac{D_L}{M_L}$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T} + 2 \times \frac{OM_T - DP_T}{F_T + G_T}\right) < \frac{D_L}{M_L}$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T} + 2 \times \frac{OM_T - DP_T}{F_T + G_T} + \frac{DP_T - MAP_T}{F_T}\right) \geq \frac{D_L}{M_L}$$

$$sep = DP_T - F_T \times \left(\frac{D_L}{M_L} - \frac{D_L + S - OM_T}{G_T} - 2 \times \frac{OM_T - DP_T}{F_T + G_T}\right) \tag{13}$$

If the trailing aircraft starts outside its outer marker and ends up inside its missed approach point:

if $OM_T < (D_L + S)$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T}\right) < \frac{D_L}{M_L}$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T} + 2 \times \frac{OM_T - DP_T}{F_T + G_T}\right) < \frac{D_L}{M_L}$$

and

$$\text{if}\left(\frac{D_L + S - OM_T}{G_T} + 2 \times \frac{OM_T - DP_T}{F_T + G_T} + \frac{DP_T - MAP_T}{F_T}\right) < \frac{D_L}{M_L}$$

$$sep = MAP_T - M_T \times \left(\frac{D_L}{M_L} - \frac{D_L + S - OM_T}{G_T} - 2 \times \frac{OM_T - DP_T}{F_T + G_T} - \frac{DP_T - MAP_T}{F_T}\right) \tag{14}$$

where sep is the separation of the the two aircraft when the leading aircraft is at the intersections. All other variables are the same as those in section A.1.

APPENDIX B

ACCELERATIONS

One of the significant factors of the missed approach analysis is the acceleration of the trailing aircraft.[1] In the previously developed simulation of missed approaches at St. Louis (Barker, 1992) the missed approach of the trailer was modeled as a multistep process. It is the purpose of this appendix to develop a simplified model based on a single step effective speed increase.

The multistep process model starts the aircraft at its missed approach point. This is followed by an intantaneous acceleration. For most aircraft this instantaneous acceleration is on the order of 10 kts and is due to configuration changes of the aircraft's control surfaces and attitude. Some aircraft, such as heavies and small general aviation aircraft, were modeled as having no instantaneous acceleration. The instantaneous acceleration is followed by a constant speed climb to 1500 feet at an aircraft dependent climb rate. Upon reaching 1500 feet, the aircraft is subjected to an aircraft dependent acceleration. If at any time during the acceleration the aircraft reaches 250 kts (the terminal control area speed limit) the acceleration is stopped and the aircraft continues at 250 kts.

The model that is used for this analysis as developed in appendix A assumes that there is a single step acceleration in order to simplify the mathematics. The single step acceleration is expressed as a factor increase in the speed of the aircraft at the point of missed approach. The objective, then, is to relate a single step acceleration to the multistep process described above. This was accomplished by determining the factor increase in speed that would place the aircraft at the intersection in the same length of time as it would take an aircraft performing the multistep process. This single step acceleration will yield equivalent results for the case where there is a heavy leader and the time separation is measured when the trailing aircraft crosses the intersection. In the case of the non-heavy leader, the separation is measured when the leading aircraft reaches the intersection and therefore prior to the time that the trailing aircraft reaches the intersection. Since the acceleration is effectively taken earlier during the single step acceleration model, the aircraft will be closer to each other at any given time prior to the time that the trailing aircraft crosses the intersection. This is consistent with the worst case philosophy of this analysis.

---

1 The leading aircraft is assumed to have no acceleration consistent with the goal of a worst case scenario.

Table B-1 shows an example of accelerating the representative set of aircraft used in the St. Louis study from the missed approach point to the intersection which is 1 nmi from the runway threshold and computing the effective speed increase factor. For some aircraft types, several final approach speeds (FAS) were assumed because those aircraft might use those speeds in various wind conditions. The climb rates were taken from the controller's handbook (FAA, 1991) and the acceleration values were determined from various sources including the aircraft operating manuals and discussions with airline representatives and pilots. This particular example shows the effect of missing at a 250 foot decision height and having a threshold-to-intersection distance of 1.00 nmi.[2]

Table B-1. Example of Effective Speed Increases

AC Type	FAS (Kts)	Climb (feet/min)	Inst. Acc (kts)	Acc2 (kts/min)	Thres to Int (nmi)	Miss Alt. (feet)	Avg. Speed (kts)	Eff. Spd. Inc. Factor
ATR42	100	1800	10	25	1.00	250.00	110.51	1.105
ATR42	120	1800	0	25	1.00	250.00	120.21	1.002
ATR42	120	1800	10	25	1.00	250.00	130.05	1.084
B727	127	2500	10	25	1.00	250.00	137.77	1.085
B747	139	2500	0	50	1.00	250.00	140.38	1.010
B747	162	2500	0	50	1.00	250.00	162.43	1.003
B747	168	2500	0	50	1.00	250.00	168.28	1.002
B767	116	2500	0	50	1.00	250.00	119.12	1.027
B767	125	2500	0	50	1.00	250.00	127.33	1.019
B767	127	3000	0	50	1.00	250.00	130.66	1.029
C172	98	650	0	25	1.00	250.00	98.00	1.000
C172	100	650	0	25	1.00	250.00	100.00	1.000
C172	120	650	0	25	1.00	250.00	120.00	1.000
F4	160	5000	20	300	1.00	250.00	197.98	1.237
F4	170	5000	20	300	1.00	250.00	205.77	1.210
L1011	131	2500	0	50	1.00	250.00	132.88	1.014
L1011	140	2500	0	50	1.00	250.00	141.32	1.009
L1011	142	2500	0	50	1.00	250.00	143.22	1.009
L1011	155	2500	0	50	1.00	250.00	155.65	1.004
L1011	157	2500	0	50	1.00	250.00	157.58	1.004
MD80	130	4000	0	75	1.00	250.00	138.24	1.063
MD80	146	4000	10	75	1.00	250.00	161.32	1.105
SW2	140	2350	0	33	1.00	250.00	140.63	1.005
SW2	140	2350	15	33	1.00	250.00	155.25	1.109

2 It is further assumed that the glide slope has the typical 3 degree elevation.

Results such as those shown in table B-1 were determined for threshold-to-intersection distances from 0 to 5 nmi in 0.5 nmi increments. This calculation was then repeated for missed approach altitudes of 250, 500, and 700 feet. Then the aircraft with the maximum percentage effective speed factor was chosen to represent each of the three groups of aircraft types. For instance, the MD80 with a final approach speed of 130 kts yields the maximum effective speed factor in the "others" category while the B767 with a final approach speed of 116 kts yields the maximum effective speed factor in the "heavies" category. The use of the maximum effective speed factor is consistent with the worst case analysis philosophy.

The results of effective speed factors plotted against the threshold-to-intersection distances are shown in figures B-1, B-2, and B-3. Each of these series of points was fitted with a cubic equation given in tables B-2, B-3, and B-4, respectively. The effective speed factor determined from these cubic equations were then used as the single-step acceleration in the model.

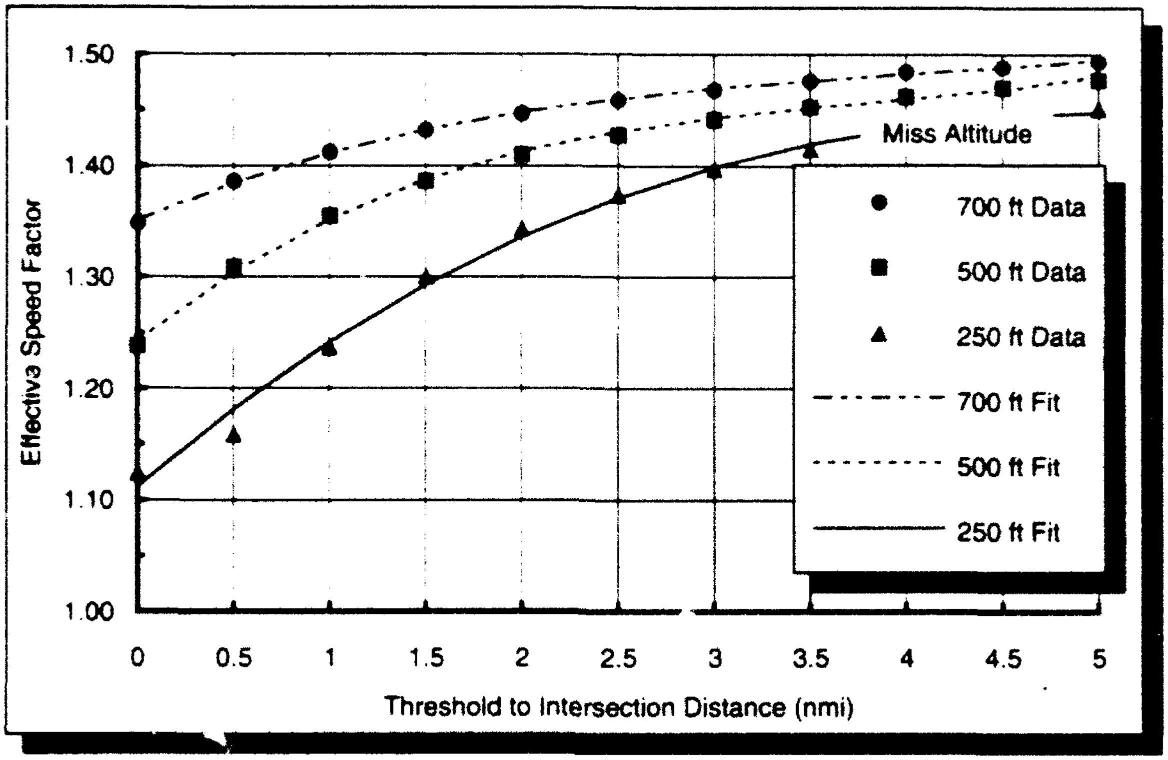

Figure B-1. Effective Speed Factors for F4s

Table B-2. Curve Fit for F4 Accelerations

Decision Height	Curve Fit Equation (x is Threshold-to-intersection Distance)
250	$1.1115+0.1494x-0.0201x^2+0.0007x^3$
500	$1.2428+0.1387x-0.0326x^2+0.0029x^3$
700	$1.3509+0.0744x-0.0154x^2+0.0013x^3$

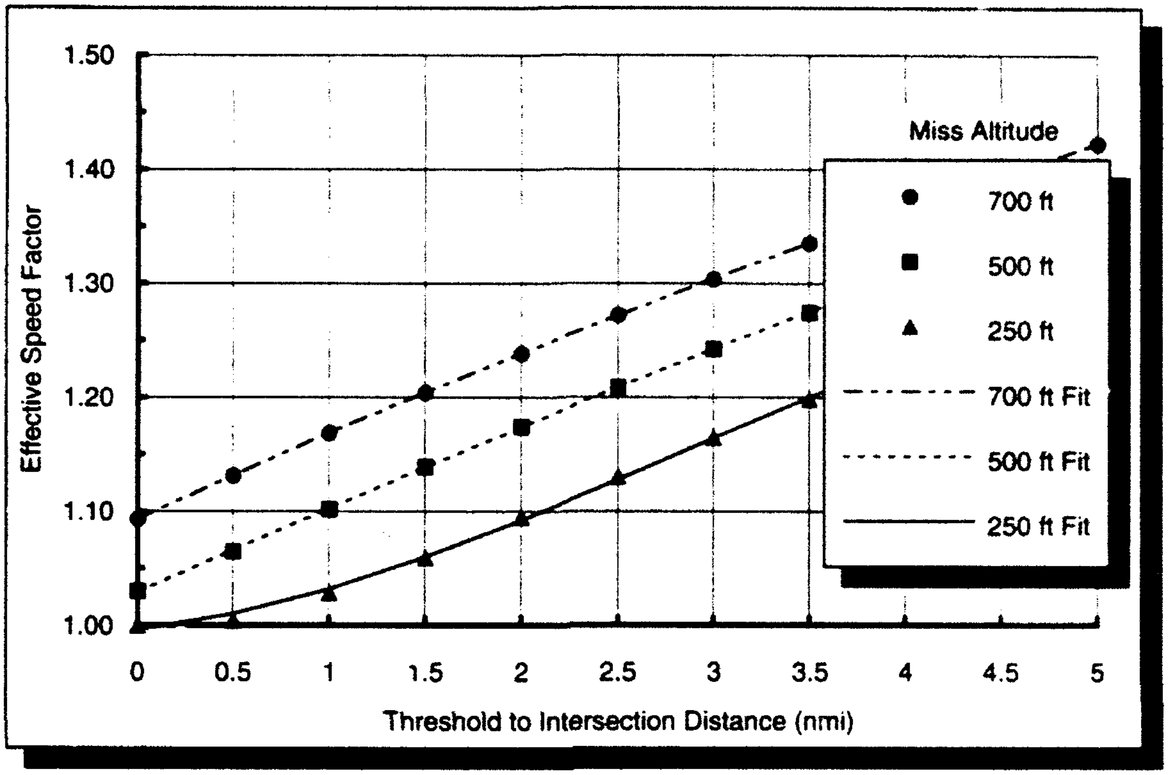

Figure B-2. Effective Speed Factors for Heavies

Table B-3. Curve Fit for Heavy Accelerations

Decision Height	Curve Fit Equation (x is Threshold-to-intersection Distance)
250	$0.9958+0.0199x+0.0184x^2-0.0021x^3$
500	$1.0293+0.0739x-0.0004x^2-0.0002x^3$
700	$1.0930+0.0785x-0.0030x^2+0.0001x^3$

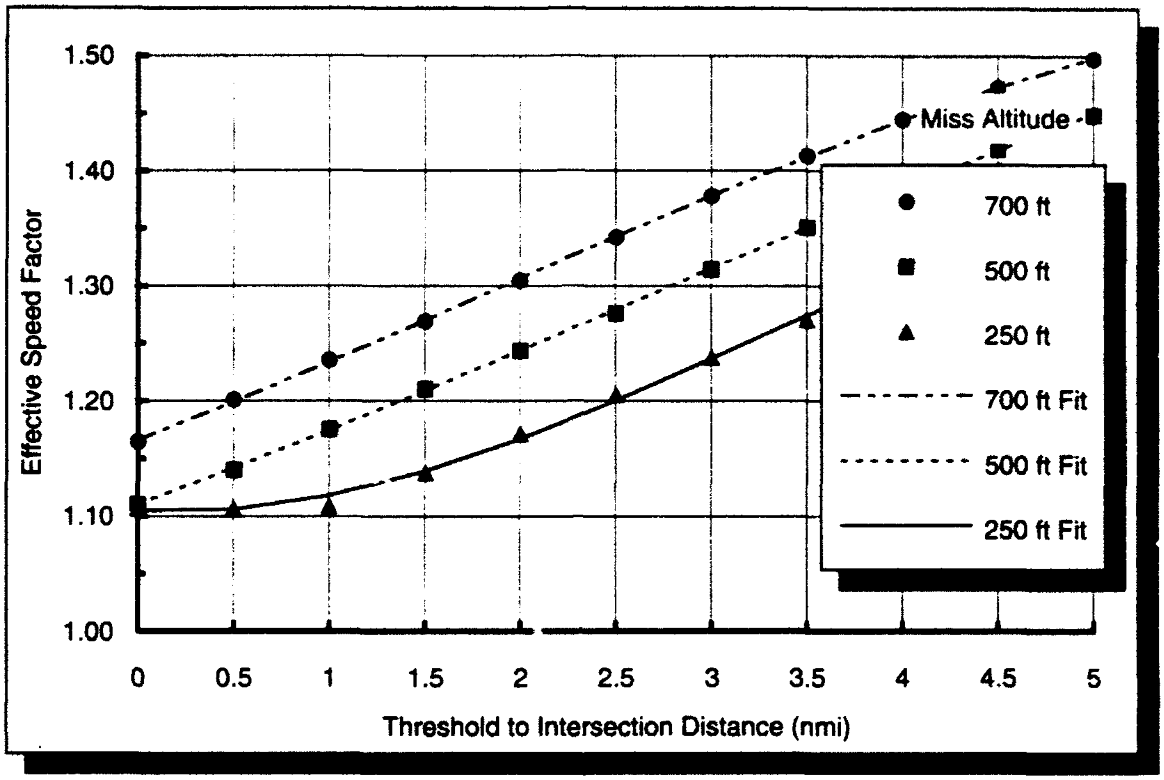

Figure B-3. Effective Speed Factors for Others

Table B-4. Curve Fit for Other Accelerations

Decision Height	Curve Fit Equation (x is Threshold-to-intersection Distance)
250	$1.1047-0.0098x+0.0256x^2-0.0026x^3$
500	$1.1103+0.0604x+0.0043x^2-0.0006x^3$
700	$1.1664+0.0635x+0.0051x^2-0.0009x^3$

APPENDIX C

WORST CASE WINDS

Since aircraft fly in an air mass which itself may be moving, the wind has a significant effect on the ground speed of an aircraft. It is the ground speed which ultimately determines the time that an aircraft takes to fly from its missed approach point to the runway centerline intersection point. This analysis, therefore, has to consider the winds.

To judge the effects of the wind, this analysis considers the worst case situation. In this case, with two aircraft making consecutive missed approaches, the worst case is where the wind either impeds the leading aircraft or assists the trailing aircraft in getting to the intersection of the runway centerlines. The slower the leading aircraft flies over the ground and the faster the trailing aircraft flies over the ground, the smaller the separation will be between the aircraft at the intersection, all other factors being equal (i.e., the initial stagger distances, final approach airspeeds, etc.).

Before determining what these worst case winds are, one has to recognize that the DCIA operation will only be conducted in certain wind conditions. Aircraft are designed to land into the wind for reasons of approach stability and roll out distance. Therefore, there are bounding conditions on the amount of headwind, tailwind and crosswind which will be tolerated during a landing. Although each airline and each private pilot have their own particular guidelines relating to these tolerances, the limits in table C-1 have been chosen for this analysis as being representative of current practices in the system.

Table C-1. Landing Wind Limits

Wind Component	Limit
Maximum Crosswind	15 kts
Maximum Tailwind	5 kts
Maximum Wind Speed	30 kts

If one were to plot out these conditions for a given runway pair, the plot would look like that shown in figure C-1. This figure is appropriate to a pair of runways with an included angle between the runways of 75 degrees. (The plot is drawn for a runway 27 and a runway 19.) The rings on the figure represent 5 kt wind speed increments. The azimuthal position around the rings indicates the direction from which the wind is blowing. The two dark lines that

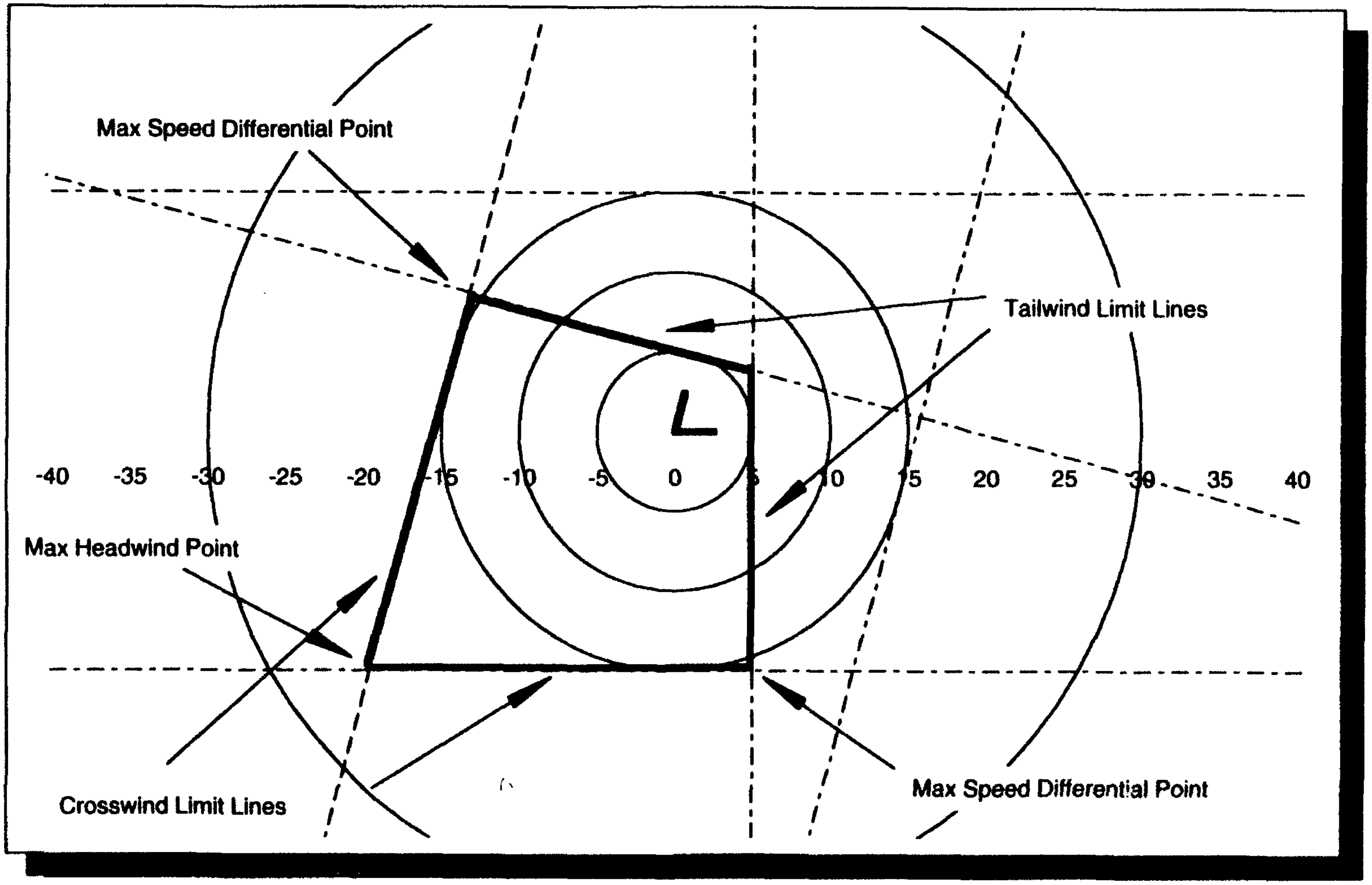

Figure C-1. Acceptable Wind Region for Runways with 75 Degree Included Angle

meet to the left in figure C-1 indicate the crosswind limits while the other two dark lines indicate the tailwind limits. Any wind condition (i.e., wind speed and wind direction) within the area bounded by the dark lines will satisfy the conditions listed in table C-1. The point where the two crosswind limit lines meet is the point at which the maximum headwind to both runways would be experienced. The points where the crosswind and tailwind limits intersect are where the maximum ground speed differential will be experienced. As explained in section 4, these two points are important in the determination of the minimum separation between the aircraft at the intersection.

Before computing what the worst case winds are for various runway configurations, let us consider in more detail the maximum headwind and the maximum differential wind points. Referring again to figure C-1, one notices that the region within the crosswind and tailwind limits is symmetrical since the same conditions apply to both runways. With a 75 degree included angle, the total wind limit of 30 kts does not come into effect. The form of this area will be basically the same for any runway pair with an included angle of greater than 60 degrees and less than or equal to 120 degrees. Figure C-2 shows the acceptable wind region for runways with an included angle of less than 60 degrees and greater than or equal to 30 degrees. For runways within this range of included angles, the total wind limit is evident as the arc between the two crosswind limit lines.

The last case to consider is the set of runway configurations where the included angle is between 90 degrees and 120 degrees. An example of the acceptable wind region for such a configuration is shown in figure C-3. In this case the wind direction and speed is the same for the maximum headwind and for the maximum differential wind.

To determine the worst case winds, the corners of the acceptable wind regions were computed for runway configurations in the range of included angles from 30 degrees to 120 degrees. The results of these computations is shown in table C-2. The maximum differential wind occurs when the included angle between the runways is approximately 110 degrees (actually 108.43 degrees). It is at this point that the wind is directly into the runway of the leading aircraft while the maximum crosswind and tailwind conditions will be applied to the trailing aircraft. The difference in groundspeeds due to the wind in this case would be 20.81 kts as shown in table C-2. The maximum headwind into the runway with the leading aircraft would be when the included angle between the runways is at a minimum of 30 degrees. The wind speed is 30 kts directly into the leading runway as shown in the table C-2. Although the speed differential in this case would be only 4.02 kts the leader would be slowed by 30 kts and in some circumstances this minimizes the separation between the aircraft at the intersection even though the trailing aircraft is slowed by 26 kts.

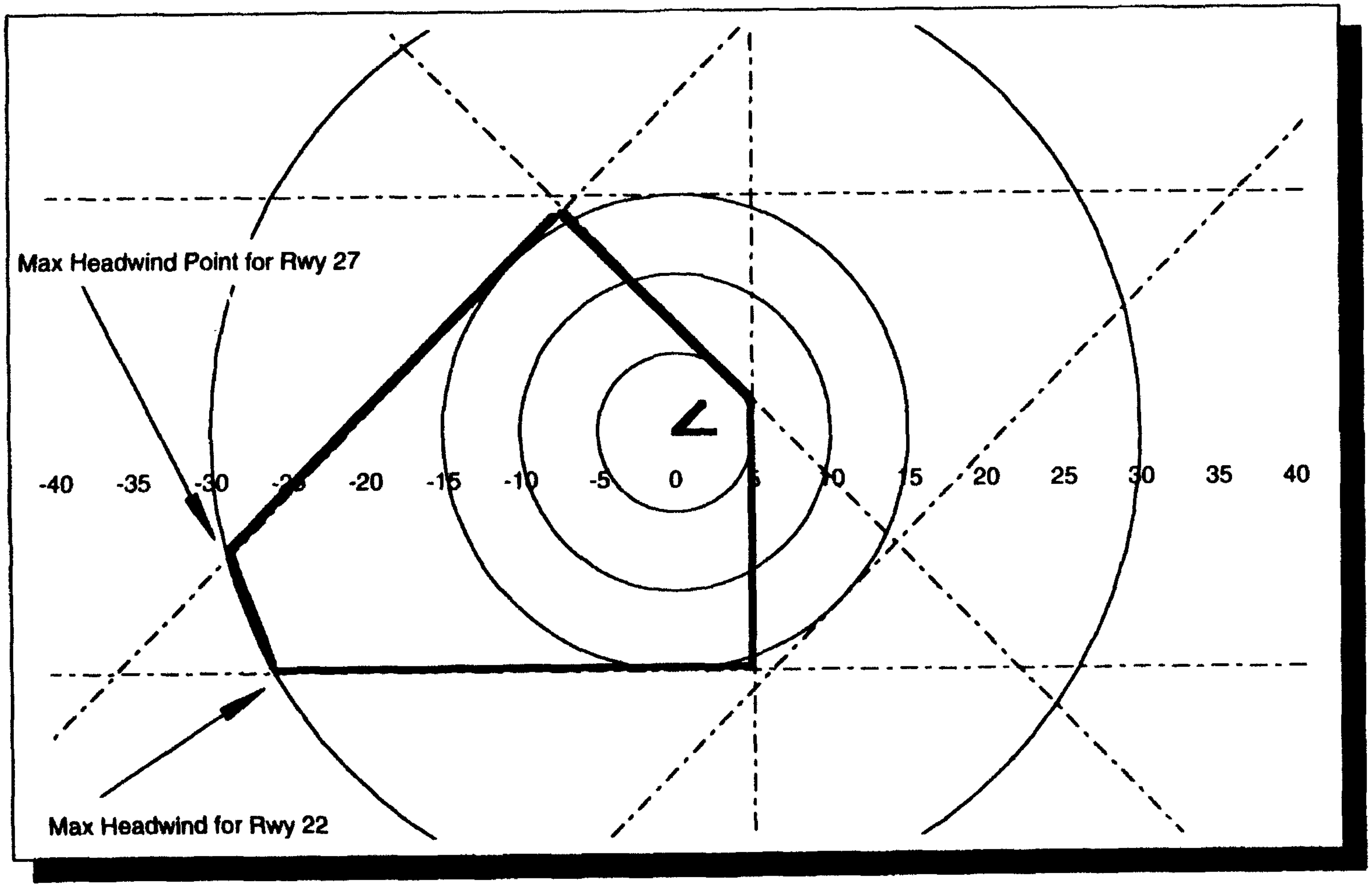

Figure C-2. Acceptable Wind Region for Runways with 45 Degree Included Angle

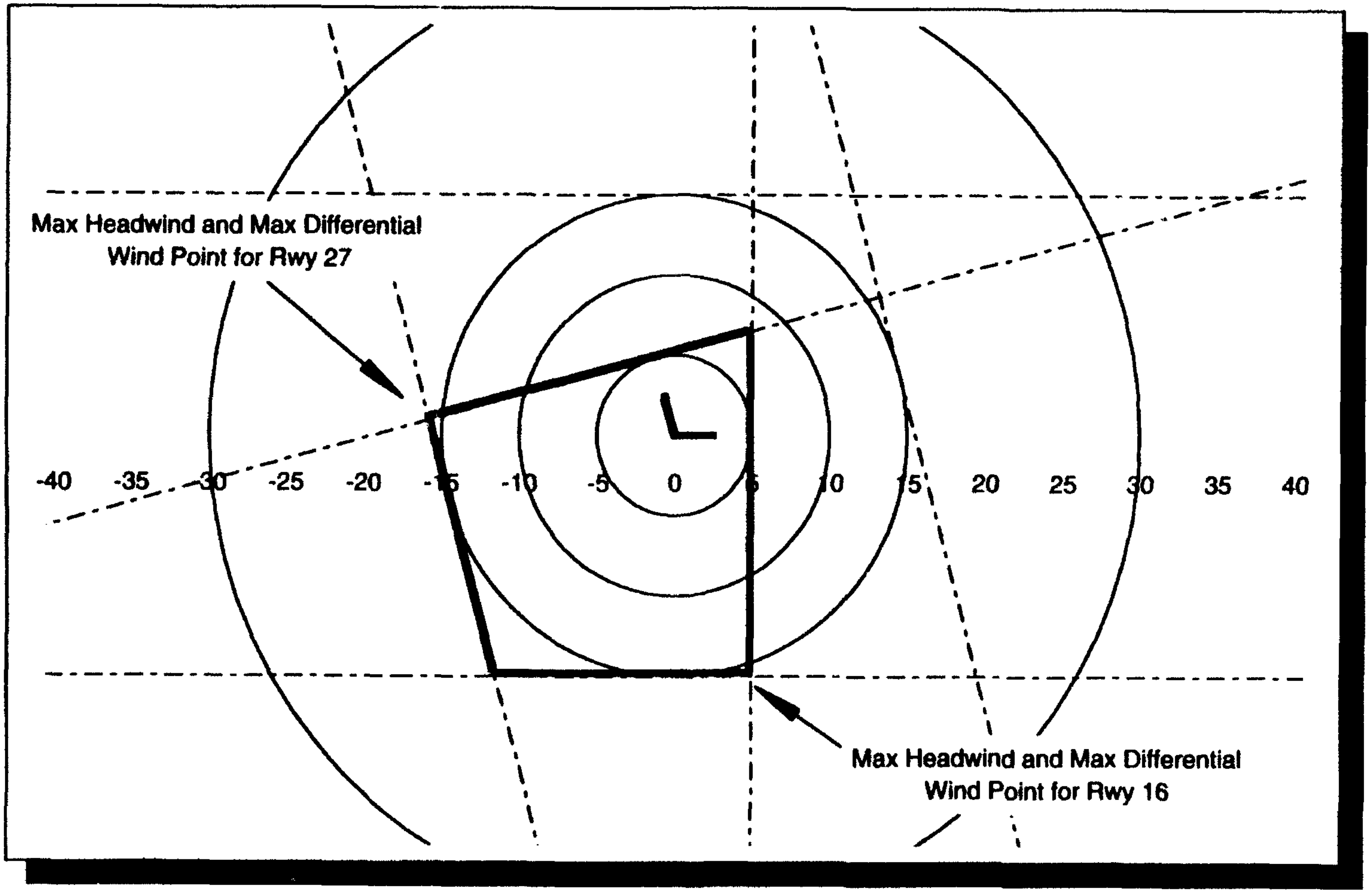

Figure C-3. Acceptable Wind Region for Runways with 105 Degree Included Angle

Table C-2. Maximum Differential and Headwinds

Included Angle Between Runways (Degs)	30	40	50	60	70	80	90	100	110	120
Maximum Differential Wind										
Wind Speed (kts)	15.53	15.81	15.81	15.81	15.81	15.81	15.81	15.81	15.81	15.81
Wind Direction (Degs)*	75.00	68.43	58.43	48.43	38.43	28.43	18.43	8.43	-1.57	-11.57
Difference in Ground Speed (kts)**	8.04	10.81	13.28	15.49	17.39	18.9	20	20.64	$\boxed{20.81}$	20.49
Maximum Headwind on Leading Aircraft										
Wind Speed (kts)	30.00	30.00	30.00	30.00	26.15	23.34	21.21			
Wind Direction (Degs)*	0.00	-10.00	-20.00	-30.00	-35.00	-40.00	-45.00	Reverts to Max Diff Wind Case		
Difference in Ground Speed (kts)**	$\boxed{4.02}$	3.56	2.21	0.00	0.00	0.00	0.00			

* Relative to bearing of runway of leading aircraft, positive toward the threshold of the other runway

** Trailing aircraft will always be faster

In the analysis described in section 4, both the maximum differential wind conditions of the 110 degree included angle case and the maximum headwind conditions of the 30 degree included angle case were used.

APPENDIX D

OBSERVATIONS OF SEPARATIONS BEHIND HEAVY AIRCRAFT

In general there are "two minute" and "five mile" rules which govern the safe separation between heavy aircraft and following aircraft. One such rule is: "Takeoff clearance to the following aircraft should not be issued until 2 minutes after the heavy jet begins takeoff roll." (FAA, 1991, Paragraph 3-108c). Because of the possible asymmetry of the runway lengths at a given airport (see section 2.2), the time separation at the intersection might be less than two minutes if the heavy aircraft is departing the runway with the longer threshold-to-intersection distance. The question is how much less can this time separation safely be.

To answer this question data was collected on the time it takes for aircraft to get to the intersection of runways 24 and 30R at St. Louis. Since it is really the time it takes for the aircraft to accelerate and cover a specific distance, several of St. Louis' runways could be used for these measurements and the appropriate distances marked corresponding to the distance along runway 30R from its threshold to the intersection of its runway centerline with runway 24 which is about 9500 feet. The reason for doing this was that departures of heavies on runway 30R are rare. Runways 30L, 12L, and 12R at St. Louis were used for this data collection. The results are shown in table D-1.

The statistics for the heavy aircraft accelerating 9500 feet is shown in table D-2.

For the non-heavy aircraft on runway 24, the time to intersection with 30R statistics are shown in table D-3.

The conclusion that one can draw from these data are that if a heavy aircraft were released as a departure on runway 30R and then 120 seconds later an aircraft is released as a departure on runway 24, then the minimum time separation at the intersection could be as low as 120-62+12=70 seconds.

As one can see from table D-1 that there were no heavies departing from runway 30R. St. Louis personnel indicated that heavies very rarely, if at all, depart on 30R. Runway 30L is preferred for heavy departures because it is a longer runway and, because of the threshold stagger, allows an operational advantage in the use of the heavy separation rule. Therefore, even though the times to the intersection imply that a 70 second separation could occur at the 24/30R intersection, in fact, it is an operation that is rarely used unless runway 30L is closed.

This being the case, further data was collected at St. Louis to establish actual observed time separations behind heavy aircraft. St. Louis commonly uses the "5 mile rule" which states

Table D-1. Times for Heavies to Accelerate 9500 feet

Aircraft Type	Time (sec)	Runway
L1011	52	12R
L1011	49	30L
L1011	52	30L
L1011	47	30L
L1011	49	30L
L1011	46	30L
L1011	52	30L
L1011	48	30L
L1011	48	30L
L1011	58	12L
L1011	54	12L
L1011	62	12L
B767	48	30L
B767	59	30L
B767	46	30L
B767	45	30L
B747	51	30L
B747	46	30L
DC8	46	12L
DC8	40	30L

Table D-2. Heavy Aircraft Time to Intersection Statistics

Number of aircraft observed	20
Mean time to "intersection"	49.9 sec
Median time to "intersection"	48 sec
Greatest time to "intersection"	62 sec
Least time to "intersection"	40 sec

Table D-3. Non-Heavy Aircraft Time to Intersection Statistics

Aircraft Type	Number	Mean Time (sec)	Range (sec)
GA	3	24	24-25
Military	2	12	12

that "the minima in paragraph 5-72d may be applied in lieu of the 2 minute requirement in paragraph 3-106f. When paragraph 5-72d minima are applied, ensure that the appropriate radar separation exists at or prior to the time an aircraft becomes airborne when taking off behind a heavy jet." (FAA, 1991, paragraph 3-106e) Paragraph 5-72d states "separate aircraft operating directly behind, or directly behind and less than 1,000 feet below, or following an aircraft conducting an instrument approach by: 1) Heavy behind heavy -- 4 miles, 2) Small/large behind heavy -- 5 miles." Paragraph 3-106f states "separate IFR/VFR aircraft taking off behind a heavy jet departure by 2 minutes when departing: 1) the same runway, 2) a parallel runway separated by less than 2,500 feet."

When departing heavy aircraft the controllers will generally release the next non-heavy aircraft on the same runway or the parallel runway when the leading heavy aircraft is 2 miles past the end of the runway as shown on the D-BRITE, because, by the time the non-heavy departure lifts off it will be 5 miles behind the leading heavy aircraft. This will, in general, result in a time separation when both aircraft are airborne of less than 2 minutes between the aircraft. Therefore, some data was collected to observe the time and distance separations of non-heavy aircraft behind heavy aircraft and is summarized in table D-4.

Table D-4. Time and Distance Separations Behind Heavy Departures

Observation Number	Time Separation (sec)	Separation behind heavy when non-heavy lift off (nmi, as observed on D-BRITE)
1	76	5
2	93	6
3	100	7
4	109	7
5	97	7

On 25 July 1991, an L1011 was observed to begin its takeoff roll on runway 30L at 9:24:55, become airborne and reach the intersection with runway 24 at 9:25:45. When the L1011 was two miles out (as shown on the D-BRITE), the local controller released the next aircraft (a commercial non-heavy jet) on runway 30L at 9:26:07. It became airborne and reached the intersection with runway 24 at 9:27:01. The intersection of runway 30L and 24 was taken as a convenient measurement point where both aircraft would be airborne. The leading heavy was 5 miles ahead of the trailing aircraft when the trailing aircraft became airborne as observed on the D-BRITE. The time separation behind the heavy aircraft when the non-heavy reached the intersection was 76 seconds.

Four other heavy departures were observed where the successive departure was fairly close behind. In those cases there was a 93 second separation with a 6 mile distance separation, a 100 second time separation with a 7 mile distance separation, a 109 second time separation with a 7 mile distance separation, and a 97 second time separation with a 7 mile distance separation.

Thus, in existing air traffic operations conducted in the current system as per (FAA, 1991), a trialing airborne non-heavy aircraft was observed to pass through airspace previously occupied by an airborne heavy aircraft within 76 seconds. This time separation was used in the analysis of the safety of the DCIA procedure.

APPENDIX E

THEORETICAL BOUNDS ON THE DIFFERENCE BETWEEN THE ORIGINAL MODEL AND THE SECOND ORDER MODEL

The theoretical bounds on the difference between the original model and the second order model were determined as follows. Since the original model and second order model have identical models for leaders, to derive an upper bound for the theoretical difference between the separations computed by the two models, it suffices to consider only trailers. This is because separation is the distance between leader and trailer when the leader is at the runway centerline intersection. The following notation, which refers only to the trailer, will be used to derive the bound:

t	=	time since trailer reached its missed approach point
T	=	time for trailer to travel from its missed approach point to the intersection (same for both models)
d	=	distance from the trailer's missed approach point to the intersection
$x_F(t)$	=	distance travelled beyond the missed approach point at time t as computed by the original model
$x_S(t)$	=	distance travelled beyond the missed approach point at time t as computed by the second order model
v	=	final approach speed of trailer
V	=	missed approach speed of trailer used in original model
P	=	V / v = ratio of trailer missed approach speed to its final approach speed in the original model
a	=	constant trailer acceleration used in missed approach maneuver in the second order model
$f(t)$	=	$x_F(t) - x_S(t)$ = difference in position (and separation) computed by the original and second order model

From elementary physics,

$$x_F(t) = V\,t$$
$$x_S(t) = v\,t + a\,t^2/2$$

Since the trailer reaches the common point at the same time in both models,

$$d = V\,T \text{ and}$$
$$d = v\,T + a\,T^2/2$$

Substituting $T = d / V$ into the last equation yields

$$d = v\,d / V + a\,(d / V)^2 / 2 \quad \text{which yields}$$
$$a = 2\,V\,(V-v) / d.$$

Hence,

$$f(t) = V\,t - v\,t - (V\,(V-v) / d)\,t^2\text{, whose derivative is}$$
$$f'(t) = V - v - 2\,(V / d)\,(V - v)\,t$$

Equating $f'(t)$ to 0 yields the time, t_{max}, at which the difference in trailer distance travelled and, hence, separation computed by the two models is maximum:

$$t_{max} = d / (2\,V) = T / 2$$

Hence, t_{max} occurs when the original model's trailer is halfway between its missed approach point and the runway centerline intersection, and this is when the orginal model's and second order model's trailer speeds are the same. Since the second order model trailer continues to accelerate, this is an intuitively appealing result. Substituting t_{max} into the expression for $f(t)$ yields the upper bound for the difference in separation between the two models:

$$f(t_{max}) = (V - v)\,d / (4\,V) = (d / 4)\,(1 - 1 / P)$$

So the upper bound on separation difference between the models is

$$B = B(d, P) = (d / 4)\,(1 - 1 / P)$$

In both models, P is computed as a function of the following arguments:

a. Trailing aircraft type: heavy; jet fighter; other
b. Decision height: up to 250 ft; between 250 and 500 ft; between 500 and 700 ft
c. Wind speed: wind that results in either maximum absolute slowing of leader or maximum slowing of leader relative to trailer

Therefore, in principal, the upper bounds for the difference in separation between the two models can be represented as a set of $3^2\,2 = 18$ functions of d (distance from trailer's missed approach point to the intersection) corresponding to the possible values of P. This can be represented as a set of 18 curves of B versus d. However, heavy trailers are not used to determine DCIA procedure restrictions and runway length breakpoints. This is because heavy aircraft accelerate less than jet fighters and other aircraft, so that the separations they engender are greater than those of the other classes of aircraft. Therefore, only 12 curves are

needed to show the theoretical bounds on the difference between the separations generated by the two models in the DCIA analysis.

These 12 curves are presented in figures E-1 through E-6. The graphs are labeled with the upper bounds of the three decision height classes (250, 500, and 700 feet); aircraft type (Other and Fighters); and wind (maximum head wind on the leader and maximum differential wind). In using the decision height values, it is assumed that aircraft fly a 3 degree glideslope. The winds that result in the maximum possible relative (relative to trailer) and absolute slowing of the lead aircraft are specified in table E-1. These are the winds that were used throughout the DCIA consecutive missed approach analysis.

Table E-1. Winds Used for DCIA Consecutive Missed Approach Analysis

Case	RWY angle (deg)	Wind Speed (kt)	Tailwind on Leader (kt)	Tailwind on Trailer (kt)
Relative (D)	110	15.8	–15.8	+5.0
Absolute (H)	30	30.0	–30.0	–26.0

For 8 specific cases, table E-2 provides a detailed comparison of the differences in separation computed by the two models versus the theoretical bounds on those differences. The 8 cases are taken from the analysis of the runway pair having threshold-to-intersection distances of 2600 and 3200 feet. These cases are all the cases in which the lead aircraft has a nominal final approach airspeed of 80 knots and the trail aircraft passed its missed approach point before the lead aircraft reached runway centerline intersection. The columns are interpreted as follows. The *Threshold-to-Intersection* columns give the distances from runway threshold to intersection for the approach paths of the *Lead* and *Trail* aircraft. *Final Approach Speed* is the nominal final approach airspeed of the trail aircraft. For *Wind Type*, *H* denotes maximum headwind and *D* denotes maximum differential wind (cf. table E-1)[1]. *Model Separation* is the distance between the modeled lead and trail aircraft when the lead aircraft is at the runway centerline intersection; it is given for both the original and second order models. *Diff. in Model Separation* is the *Observed* difference between the two model separations and the corresponding theoretical *Bound* on the difference. Note that model

1 In table E-1, H is called the Absolute case and D is called the Relative case.

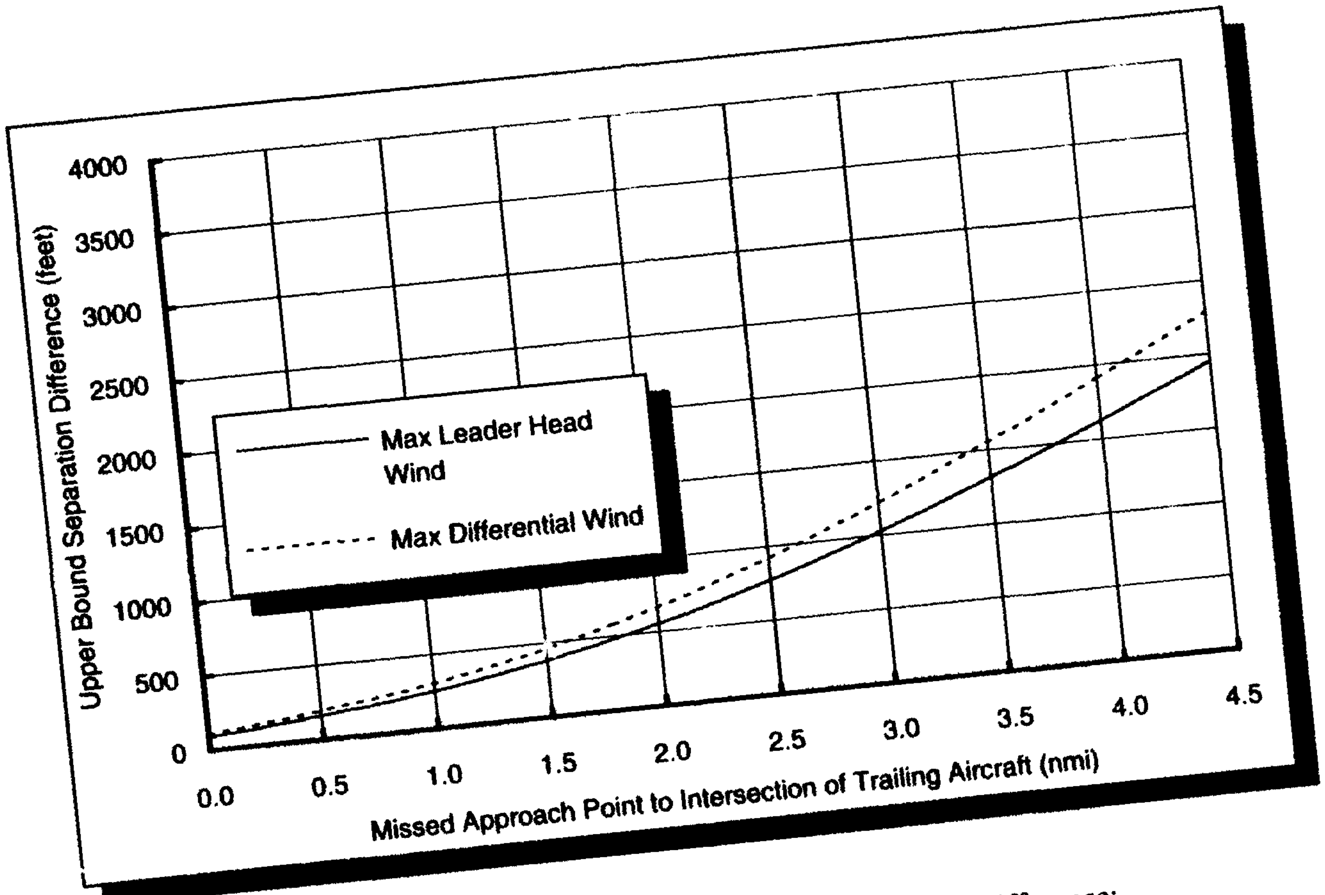

Figure E-1. Theoretical Upper Bound on Separation Difference: Decision Height = 250 Feet and Trailing Aircraft = Other

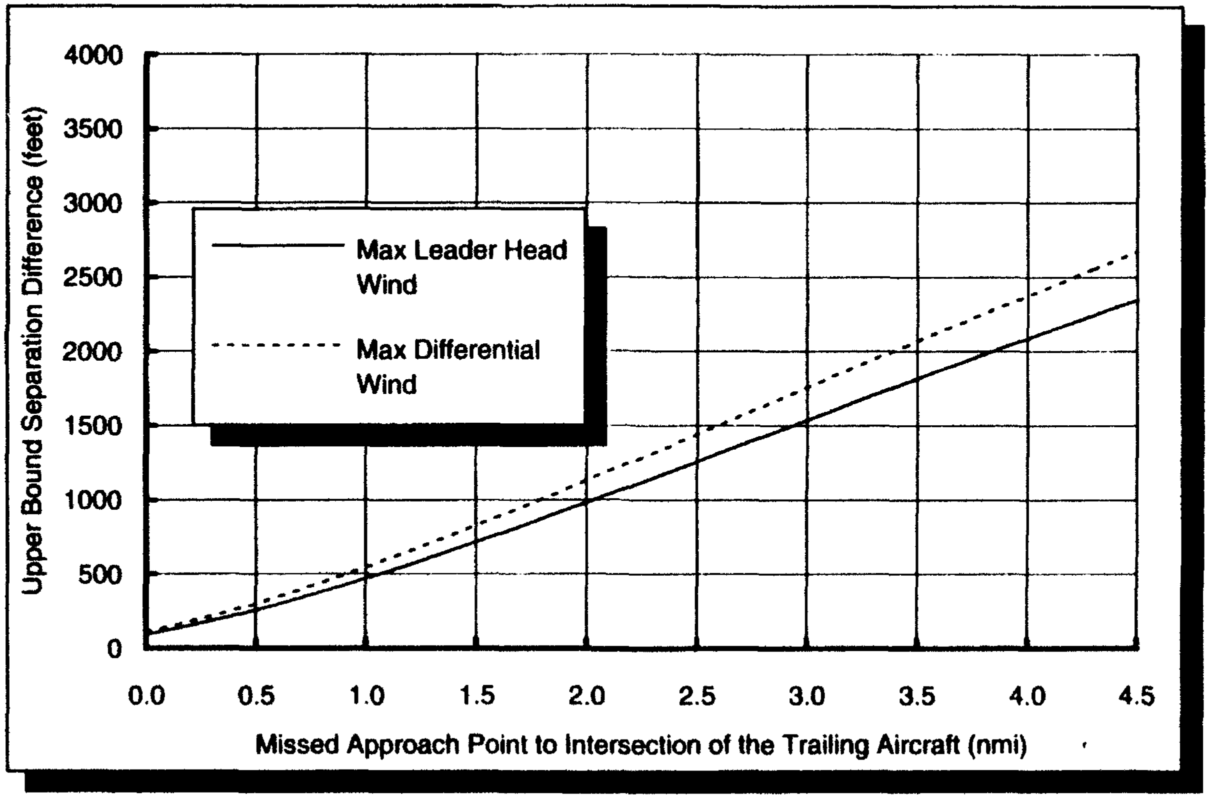

Figure E-2. Theoretical Upper Bound on Separation Difference:
Decision Height = 250 Feet and Trailing Aircraft = Fighter

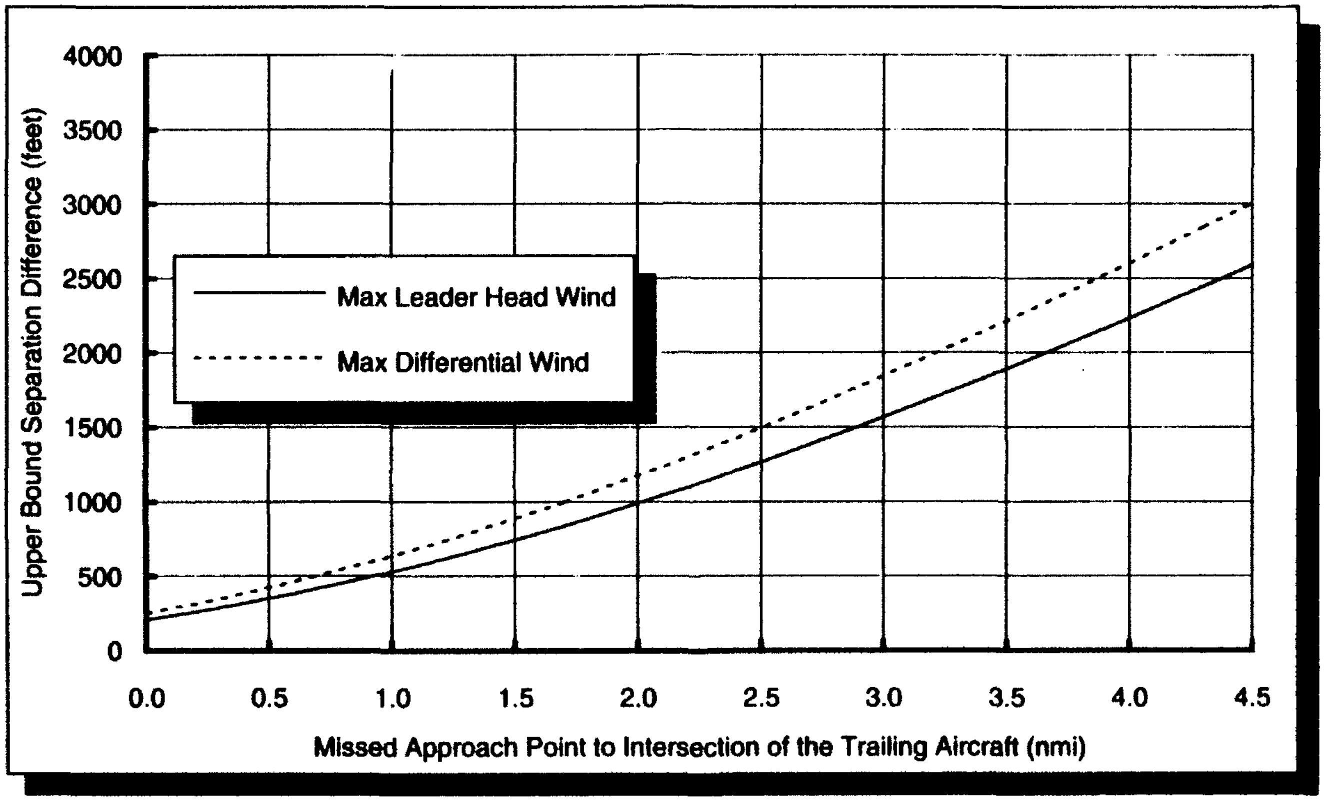

Figure E-3. Theoretical Upper Bound on Separation Difference:
Decision Height = 500 Feet and Trailing Aircraft = Other

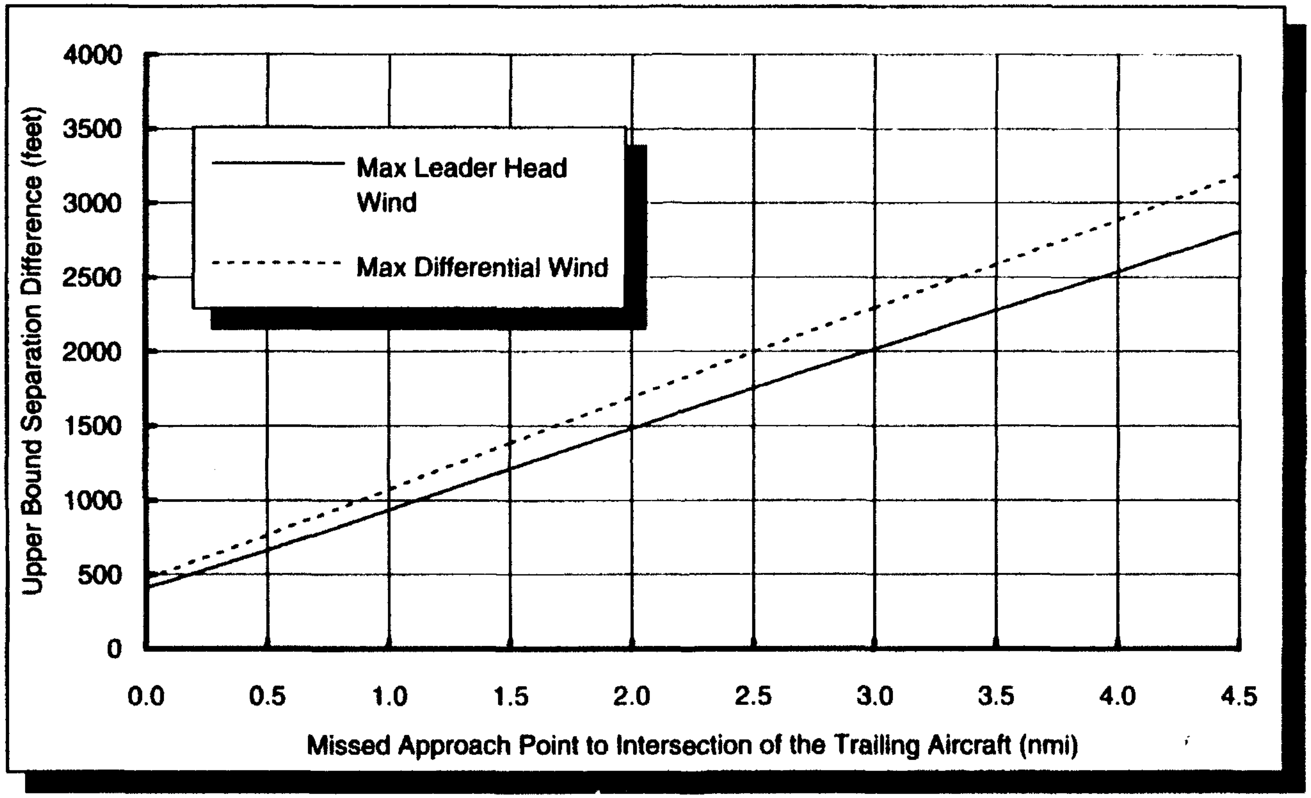

Figure E-4. Theoretical Upper Bound on Separation Difference:
Decision Height = 500 Feet and Trailing Aircraft = Fighter

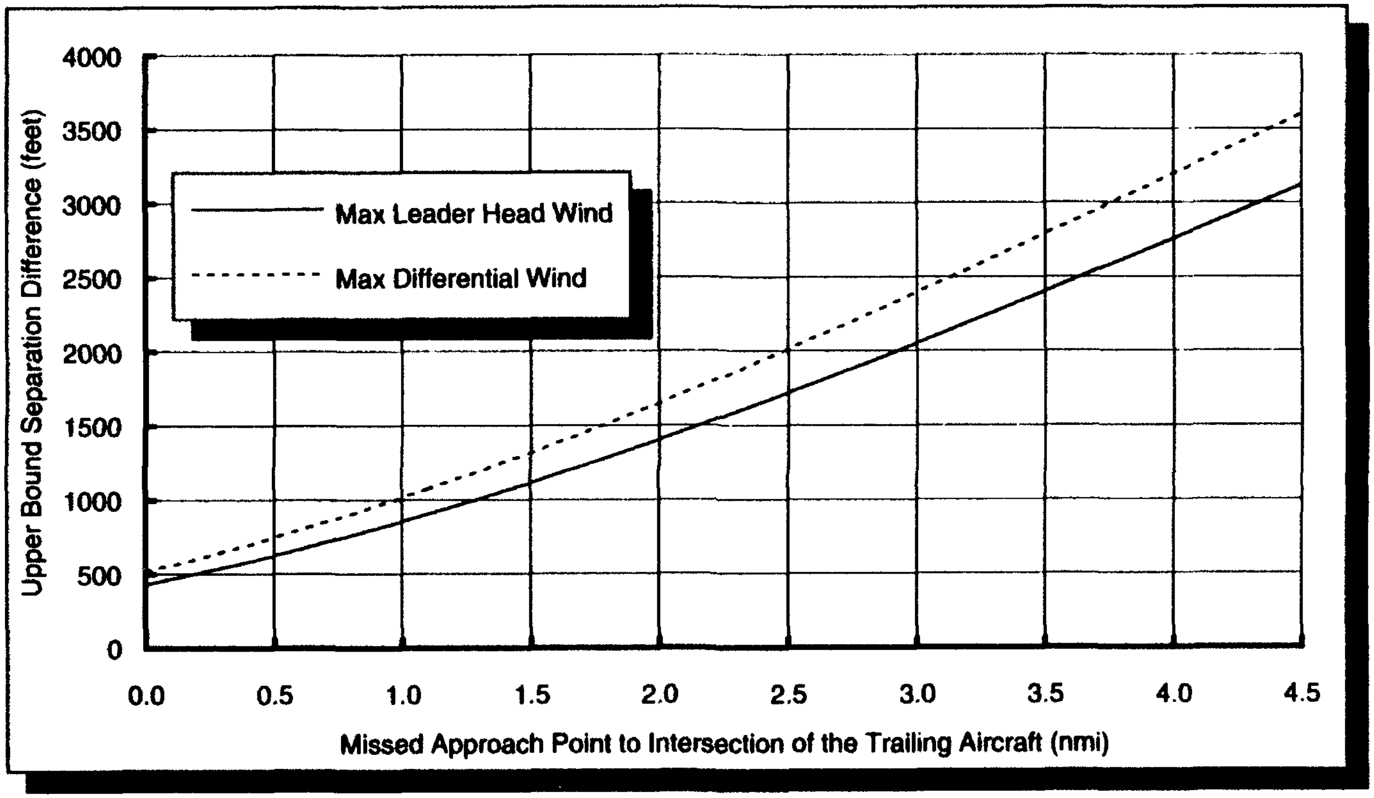

Figure E-5. Theoretical Upper Bound on Separation Difference:
Decision Height = 700 Feet and Trailing Aircraft = Other

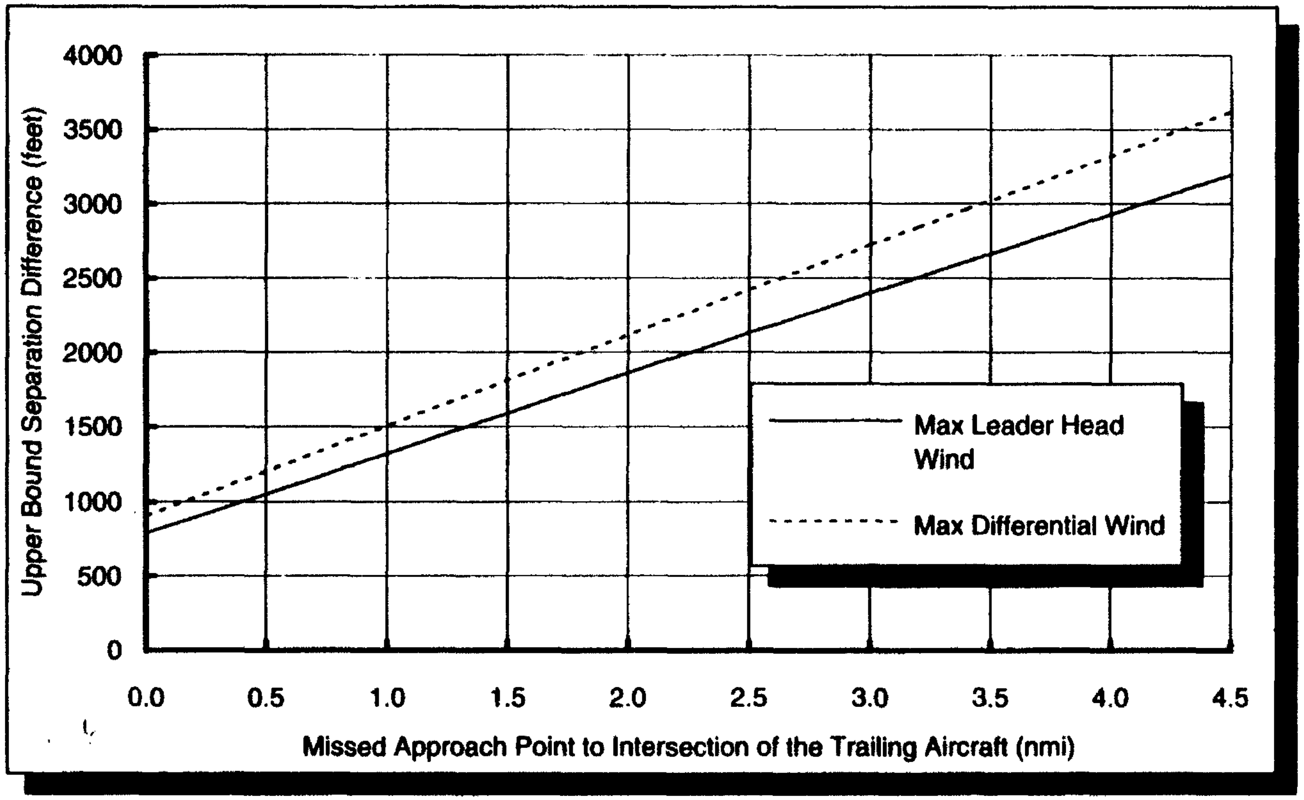

Figure E-6. Theoretical Upper Bound on Separation Difference: Decision Height = 500 Feet and Trailing Aircraft = Fighter

Table E-2. Some Differences in Separation Distances for the Original and Second Order Models

Threshold-to-Intersection (ft)		Final Approach Speed	Wind Type	Model Separation (nmi)		Diff. in Model Separation (ft)		Observed ÷ Bound
Lead	Trail	(kt)	(H / D)	Original	2nd Order	Observed	Bound	(%)
3200	2600	150	H	1.0246	1.0280	21	180	12
3200	2600	160	H	0.8817	0.9064	150	272	55
3200	2600	160	D	1.0175	1.0228	32	229	14
3200	2600	170	H	0.7415	0.7786	225	269	84
3200	2600	170	D	0.9138	0.9314	107	230	47
2600	3200	160	H	1.1068	1.1151	50	316	16
2600	3200	170	H	0.9912	1.0163	153	313	49
2600	3200	170	D	1.1302	1.1339	22	267	8

separations are given in nmi, and the differences and corresponding bounds are given in feet. Finally, the ratio of the observed difference in model separation to the corresponding theoretical bound is expressed in the rightmost column as a percent.

APPENDIX F

ST. LOUIS AUTHORIZATION

This appendix contains the waiver that allowed St. Louis to conduct stagger operations in instrument meteorological conditions during the evaluation.

U.S. Department of Transportation

Federal Aviation Administration

Memorandum

Subject: INFORMATION: Request for Waiver to Order 7110.65F, Paragraph 5-72, and paragraph 5-114 for St. Louis, MO (STL) ATCT

Date: SEP 3 199!

From: Director, Air Traffic Rules and Procedures Service, ATP-1

Reply to Attn. of:

To: Manager, Air Traffic Division, ACE-500

The attached waiver permits the STL ATCT to conduct dependent converging instrument approaches in accordance with the prescribed procedures contained in Waiver 91-25-120.

The waiver/authorization is effective September 3, 1991 and is valid for 2 years. Request for renewal of this waiver should be made at least 120 days prior to its expiration date of September 2, 1993.

Original Signed By
Theodore H. Davies
L. Lane Speck

Attachment

Waiver 91-25-120
Date: 9/3/91

FEDERAL AVIATION ADMINISTRATION
AIR TRAFFIC DIRECTIVES
WAIVER/AUTHORIZATION

ISSUED TO:

Manager, Air Traffic Division, ACE-500, for St. Louis Airport (STL) ATCT.

AFFECTED DIRECTIVE(S):

Order 7110.65, Paragraph 5-72.
Order 7110.65, Paragraph 5-114.

OPERATIONS AUTHORIZED:

This waiver authorizes the STL ATCT:

1. To conduct dependent converging instrument approaches (DCIA) during instrument flight rules conditions, using the converging runway display aid (CRDA), to Runways 24 and 30R.

2. To utilize a minimum of 2NM lateral separation between aircraft established on converging localizers.

3. To utilize less than 2NM separation between a missed approach aircraft on either Runway 30R or Runway 24 and an arrival on the converging runway.

SPECIAL PROVISIONS, CONDITIONS, LIMITATIONS:

The following items are required for conducting DCIA:

1. 2NM or more intrail spacing between a leading non-heavy aircraft and a trailing aircraft on approach to the converging runway when the leading aircraft is at the landing threshold.

2. 5NM or more intrail spacing between a leading heavy aircraft and a trailing aircraft on approach to the converging runway when the leading aircraft is at the landing threshold.

3. Operating control tower.

4. Operating airport surveillance radar (ASR) and CRDA.

5. Nonintersecting final approach courses.

6. A facility directive specifying, as a minimum:

   (a) Each applicable runway configuration.

   (b) Coordination requirements.

   (c) Weather minima applicable to each configuration if different from published minima.

7. Direct communications capability between the final approach control position for each converging runway and the associated local control position.

8. Only straight-in approaches will be made.

9. Navigational aids and air traffic control frequencies shall be operating properly. Minimum requirements are a localizer operating on each runway.

10. Aircraft shall be informed on initial contact or as soon as possible thereafter that dependent converging approaches are in use. This information may be provided through the automated terminal information service (ATIS).

11. All single engine or non turbo twin engine aircraft shall utilize Runway 24.

12. All heavy aircraft shall utilize Runway 30R.

13. Aircraft with final approach speeds greater than 150 knots are not authorized to participate in the DCIA procedure.

REPORTING REQUIREMENTS:

1. Record any occurrence of consecutive missed approaches on the Daily Record of Facility Operation, Form 7230.4, and submit a brief summary to the Air Traffic Procedures Division, ATP-100, through ACE-500, within 72 hours. Include aircraft identification, type, weather, reason for each of the missed approaches, and any other pertinent data. Consecutive missed approaches are defined as two missed approaches by aircraft on two converging approaches occurring within 2 minutes of each other.

2. Notify ATP-100 within 24 hours of any operational error/deviation, pilot deviation, TCAS resolution advisory, or near mid-air collision report involving the CRDA.

3. Provide ATP-100 with a monthly report on the number of aircraft that utilize CRDA under the provisions of this waiver.

This waiver is effective September 3, 1991 and is valid for 2 years. A request for renewal of this waiver should be made at least 120 days prior to the expiration date.

Theodore H Davies
for L. Lane Speck
Director, Air Traffic
Rules and Procedures Service, ATP-1

APPENDIX G

COMPARISON OF FIRST AND SECOND ORDER MODEL PROCEDURES FOR DECISION HEIGHTS OF 250 FT OR LESS

Table G-1 in this appendix presents the operational benefits to table 5-2 that result from using the second order model rather than the model described in section 3. The second order model is described in section 4.2. As explained in section 5.3.2, table G-1 also serves to corroborate table 5-2. Section 5.3.2 includes an explanation of the requirements that were imposed when applying the second order model to develop table G from table 5-2.

All but the rightmost column of table G-1 is the same as that of table 5-2. The rightmost column of table G-1 specifies the increases in "Longer distance from threshold to intersection" and the weakening in the restrictions in table 5-2 that result from using the second order model.

Table G-1. Comparison of First and Second Order Model Procedures for Decison Heights of 250 Feet or Less

	Shorter distance from threshold to intersection	Longer distance from threshold to intersection	DCIA Procedure Stagger aircraft to converging runways using indicated stagger distance; restrictions noted	Modifications and Comments Based on Second Order Analysis
1	Up to 2600 ft	Up to 2600 ft	● None; stagger rule is (2,5)	None
2	Up to 2600 ft	2601 ft to 3200 ft	● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Except 160 kt or greater aircraft; stagger rule is (2,5) or ● None; stagger rule is (2.5,5)	None
3	Up to 2600 ft	3201 ft to 4500 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or	All rules confirmed. Rule 5 can be weakened:

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● None; stagger rule is (3,5)	● Do not pair 80 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,5)
4	*Up to* 2600 ft	4501 ft to 5900 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or	None

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5)	
5	Up to 2600 ft	5901 ft to 7500 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5)	All rules confirmed. Rule 6 can be weakened: ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5)

6	Up to 2600 ft	7501 ft to 9700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	All rules confirmed. Rules 3 and 5 can be weakened: ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5) ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,6)
7	Up to 2600 ft	9701 ft to 10600 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or	The longer threshold-to-intersection distance extends to 12500 ft. With this increased distance, rule 1 still holds, rules 2 and 3 fail, and rules 4 and 5 must be replaced:

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	● Restrict 110 kt or less aircraft leading to runway with shorter threshold to intersection distance and do not pair 120 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,6) ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
8	Up to 2600 ft	10601 ft to 12200 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	Superseded by revised box 7
9	Up to 2600 ft	12201 ft to 13900 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	None

10	Up to 2600 ft	13901 ft to 17600 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,6)	None
11	Up to 2600 ft	17601 ft to 19700 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,6)	No extension of the longer threshold-to-intersection distance found.
12	2601 ft to 3400 ft	Up to 3400 ft	● Except 80 kt or less aircraft; stagger rule is (2,5) or ● None; stagger rule is (2.5,5)	None
13	2601 ft to 3400 ft	3401 ft to 4000 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft; stagger rule is (2,5) or ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (2,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● None; stagger rule is (3,5)	The longer threshold-to-intersection distance extends to 4500 with all rules confirmed.
14	2601 ft to 3400 ft	4001 ft to 5800 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (2,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or	The longer threshold-to-intersection distance extends to 5900 with all rules confirmed.

			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	
15	2601 ft to 3400 ft	5801 ft to 7500 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	The longer threshold-to-intersection distance extends to 7600 with all rules confirmed.
16	2601 ft to 3400 ft	7501 ft to 9700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	The longer threshold-to-intersection distance extends to 9800 with all rules confirmed. Rules 4 and 5 can be weakened:

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or	
			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6) or	● Restrict 100 kt or less aircraft leading to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6)
			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
17	2601 ft to 3400 ft	9701 ft to 12100 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (2,5,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or	The longer threshold-to-intersection distance extends to 12600 with rule 1 confirmed. For this extended distance, rules 2 and 3 fail, but rules 4 and 5 can be weakened:
			● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6) or	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 120 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6)

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
18	2601 ft to 3400 ft	12101 ft to 13900 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 14100. For this extended distance, both rules can be weakened: ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,6) ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
19	2601 ft to 3400 ft	13901 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,6)	None
20	3401 ft to 4400 ft	Up to 4400 ft	● Except 80 kt or less aircraft and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5,5) or ● None; stagger rule is (3,5)	None
21	3401 ft to 4400 ft	4401 ft to 5800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2,5) or	The longer threshold-to-intersection distance extends to 7400. For this extended distance, rules 1 and 2 are confirmed; rule 3 fails; and stronger versions of rules 4, 5, 6, and 7 are needed:

			● Except 90 kt or less aircraft and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or	
			● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or	
			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 100 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,5)
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 100 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,5)
			● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5) or	● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,5)
			● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,5)
22	3401 ft to 4400 ft	5801 ft to 7400 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or	Superseded by extension of box 21

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance; stagger rule is (3,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	
23	3401 ft to 4400 ft	7401 ft to 9600 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6) or	The longer threshold-to-intersection distance extends to 9800. For this extended distance, all rules are confirmed, but rules 4 and 5 can be relaxed: ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,6)

			● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
24	3401 ft to 4400 ft	9601 ft to 12200 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 12600. For this extended distance, rule 1 is confirmed, rules 2 and 3 fail, rule 4 is confirmed, and rule 5 can be weakened: ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)
25	3401 ft to 4400 ft	12201 ft to 13900 ft	● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,6) or	The longer threshold-to-intersection distance extends to 17800. For this extended distance, rule 1 is confirmed; and rules 2 and 3 need to be strengthened:

			● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,6)	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 120 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6) ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 120 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
26	3401 ft to 4400 ft	13901 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,6)	Superseded by revised box 25
27	4401 ft to 5700 ft	Up to 5700 ft	● Except 90 kt or less aircraft and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5) or ● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2,5) or ● Except 80 kt or less aircraft and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	All rules confirmed. Rule 1 can be weakened: ● Except 90 kt or less aircraft and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2,5)
28	4401 ft to 5700 ft	5701 ft to 6500 ft	● Except 80 kt or less aircraft and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 80 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	None

29	4401 ft to 5700 ft	6501 ft to 7200 ft	● Except 80 kt or less aircraft and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 80 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (3,5)	No extension of the longer threshold-to-intersection distance found.
30	4401 ft to 5700 ft	7201 ft to 12100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,6) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft with 160 kt or greater aircraft; stagger rule is (3,6)	No extension of the longer threshold-to-intersection distance found.
31	4401 ft to 5700 ft	12101 ft to 13800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	No extension of the longer threshold-to-intersection distance found.
32	4401 ft to 5700 ft	13801 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 18000 with rule confirmed.

33	5701 ft to 6400 ft	Up to 6400 ft	● Except 80 kt or less aircraft and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Except 80 kt or less aircraft; stagger rule is (3,5)	None
34	5701 ft to 6400 ft	6401 ft to 6900 ft	● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft; stagger rule is (3,5) or ● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,5)	No extension of the longer threshold-to-intersection distance found.
35	5701 ft to 6400 ft	6901 ft to 10800 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 11100 with all rules confirmed. Rule 3 can be weakened: ● Except 80 kt or less aircraft and restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (3,6)
36	5701 ft to 6400 ft	10801 ft to 12100 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or	No extension of the longer threshold-to-intersection distance found.

			● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 120 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	
37	5701 ft to 6400 ft	12101 ft to 13800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,6) or ● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 14100 with both rules confirmed. Rule 2 can be weakened: ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance and do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)
38	5701 ft to 6400 ft	13801 ft to 17800 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 18100.
39	6401 ft to 8300 ft	Up to 8300 ft	● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2.5,6) or	All rules confirmed.

			● Do not pair 90 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	
40	6401 ft to 8300 ft	8301 ft to 8700 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (2.5,5) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and except 80 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (2.5,6) or ● Restrict 90 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 80 kt or less aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 11000 with rules 1, 2, and 4 confirmed. Rule 3 needs to be strengthened: ● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 120 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance; stagger rule is (2.5,6)
41	6401 ft to 8300 ft	8701 ft to 11100 ft	● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 11300. Rule can be weakened: ● Do not pair 100 kt or less aircraft leading with 160 kt or greater aircraft trailing and do not pair 110 kt or less aircraft leading on runway with longer threshold to intersection distance with 160 kt or greater aircraft trailing on runway with shorter threshold to intersection distance and except 80 kt or less aircraft; stagger rule is (3,6)
42	6401 ft to 8300 ft	11101 ft to 14000 ft	● Restrict 100 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 14300.
43	6401 ft to 8300 ft	14001 ft to 17700 ft	● Restrict 110 kt or less aircraft to runway with shorter threshold to intersection distance and except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,6)	The longer threshold-to-intersection distance extends to 18100.

44	8301 ft to 10800 ft	Up to 10800 ft	● Except 90 kt or less aircraft and except 160 kt or greater aircraft; stagger rule is (3,5) or ● Do not pair 110 kt or less aircraft leading with 160 kt or greater aircraft trailing and except 90 kt or less aircraft; stagger rule is (3,6)	Both threshold-to-intersection distances extend to 11100 with rules confirmed.

GLOSSARY

AGL	Above Ground Level
ARTS IIIA	Automated Radar Terminal System Model IIIA
ATC	Air Traffic Control
CRDA	Converging Runway Display Aid
D-BRITE	Digital Bright Radar Indicator Tower (Terminal) Equipment
DCIA	Dependent Converging Instrument Approach
FAA	Federal Aviation Administration
FMS	Flight Management System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MLS	Microwave Landing System
RNAV	Area Navigation
SCIA	Simultaneous Converging Instrument Approaches
TATCA	Terminal ATC Automation
TCAS	Traffic Alert and Collision Avoidance System
TRACON	Terminal Radar Approach Control Facility
VMC	Visual Meteorological Conditions
VOR	Very High Frequency Omnidirectional Range